

# Geology and Mineralogy of Carbonate-Hosted Nonsulphide Zn-Pb Mineralization in Southern (NTS 082F/03) and Central (NTS 093A/14E, 15W) British Columbia

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Paradis, S., Keevil, H., Simandl, G.J. and M. Raudsepp (2011): Geology and mineralogy of carbonate-hosted nonsulphide Zn-Pb mineralization in southern (NTS 082F/03) and central (NTS 093A/14E, 15W) British Columbia; in Geoscience BC Summary of Activities 2010, Geoscience BC, Report 2011-1, p. 143–168.

## Introduction

Nonsulphide deposits were the main source of zinc prior to the 1930s, but following the development of differential flotation and breakthroughs in smelting technology, the mining industry turned its attention to sulphide ore. Today, most zinc is derived from sulphide ore (Hitzman et al., 2003; Simandl and Paradis, 2009), yet recently, the successful operation of a dedicated processing plant to extract zinc metal (through direct acid leaching, solid-liquid separation, solvent extraction and electrowinning) from nonsulphide and mixed ores, mined at the Skorpion mine in Namibia, has put nonsulphide Zn-Pb deposits back into the limelight.

Carbonate-hosted, nonsulphide base-metal (CHNSBM) deposits form in supergene environments from sulphide deposits such as Mississippi Valley-type (MVT), sedimentary exhalative-type (SEDEX), Irish-type and vein-type deposits and, to lesser extent, skarns. Several carbonate-hosted sulphide deposits in the Kootenay terrane, adjacent Cariboo terrane and, elsewhere in BC, have near-surface Zn- and Pb-bearing iron-oxide gossans (Simandl and Paradis, 2009; Paradis et al., 2010). Such gossans form when carbonate-hosted base-metal sulphide mineralization is subject to intense weathering and metals are liberated by the oxidation of sulphide minerals. The metals can be trapped locally, forming direct-replacement, nonsulphide ore deposits, or they can be transported by percolating waters down and away from the sulphide protore (primary ore), forming wallrock-replacement CHNSBM deposits (Heyl and Bozion, 1962; Hitzman et al., 2003; Simandl and Paradis, 2009). Wallrock-replacement deposits can be lo-

cated in proximity to protore or up to several hundreds of metres away (Heyl and Bozion, 1962; Hitzman et al., 2003; Reichert and Borg, 2008; Reichert, 2009). The direct-replacement nonsulphide deposits are also known as ‘red ores’ because they consist commonly of iron oxyhydroxides, goethite, hematite, hemimorphite, smithsonite, hydrozincite and cerussite; they typically contain >20% Zn, >7% Fe and Pb±As. The wallrock-replacement deposits, also known as ‘white ores’, consist of smithsonite, hydrozincite and minor iron oxyhydroxides, and contain <40% Zn, <7% Fe and very low concentrations of Pb. Wallrock-replacement deposits are commonly rich in Zn and poor in Pb relative to the direct-replacement CHNSBM deposits (Simandl and Paradis, 2009) and, from a metallurgical and environmental perspective, white ores are simpler and preferable.

Historically, it was assumed that British Columbia did not have a significant potential to host economic CHNSBM deposits because it had been subjected to several periods of glaciation. It is now well established, that given favourable morphology and orientation, CHNSBM deposits can survive glaciations (Simandl and Paradis, 2009; Paradis et al., 2010), making these deposits legitimate exploration targets in the province.

The primary objective of this paper is to define the geological and mineralogical attributes of representative CHNSBM deposits in southern and central BC (Figure 1), which will also provide the foundation for the B.Sc. honours thesis of H. Keevil. These attributes could be used as a tool for the identification of areas of maximum prospectivity in southern and central BC, as well as elsewhere in the province.

## Regional Geology

The areas of interest are located in the Salmo camp of the southern Kootenay Arc in southeastern BC (NTS 082F/03) and at the Cariboo Zinc property in the Quesnel Lake area of east-central BC (NTS 093A/14E, 15W; Figure 1).

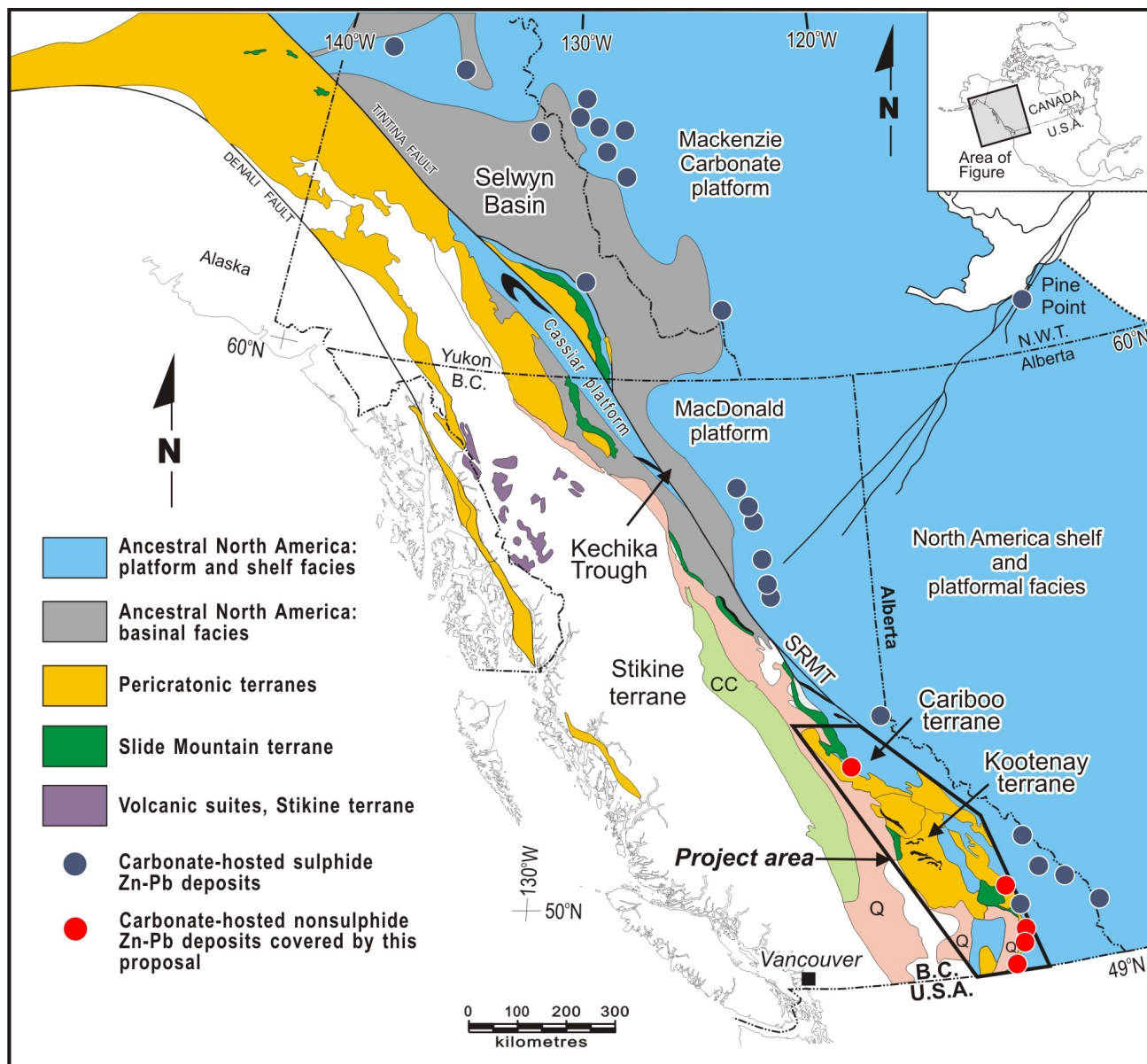
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**Keywords:** zinc-lead deposits, nonsulphides, carbonate-hosted, sphalerite, galena, pyrite, hemimorphite, cerussite, smithsonite, oxide, Salmo district, Quesnel Lake area

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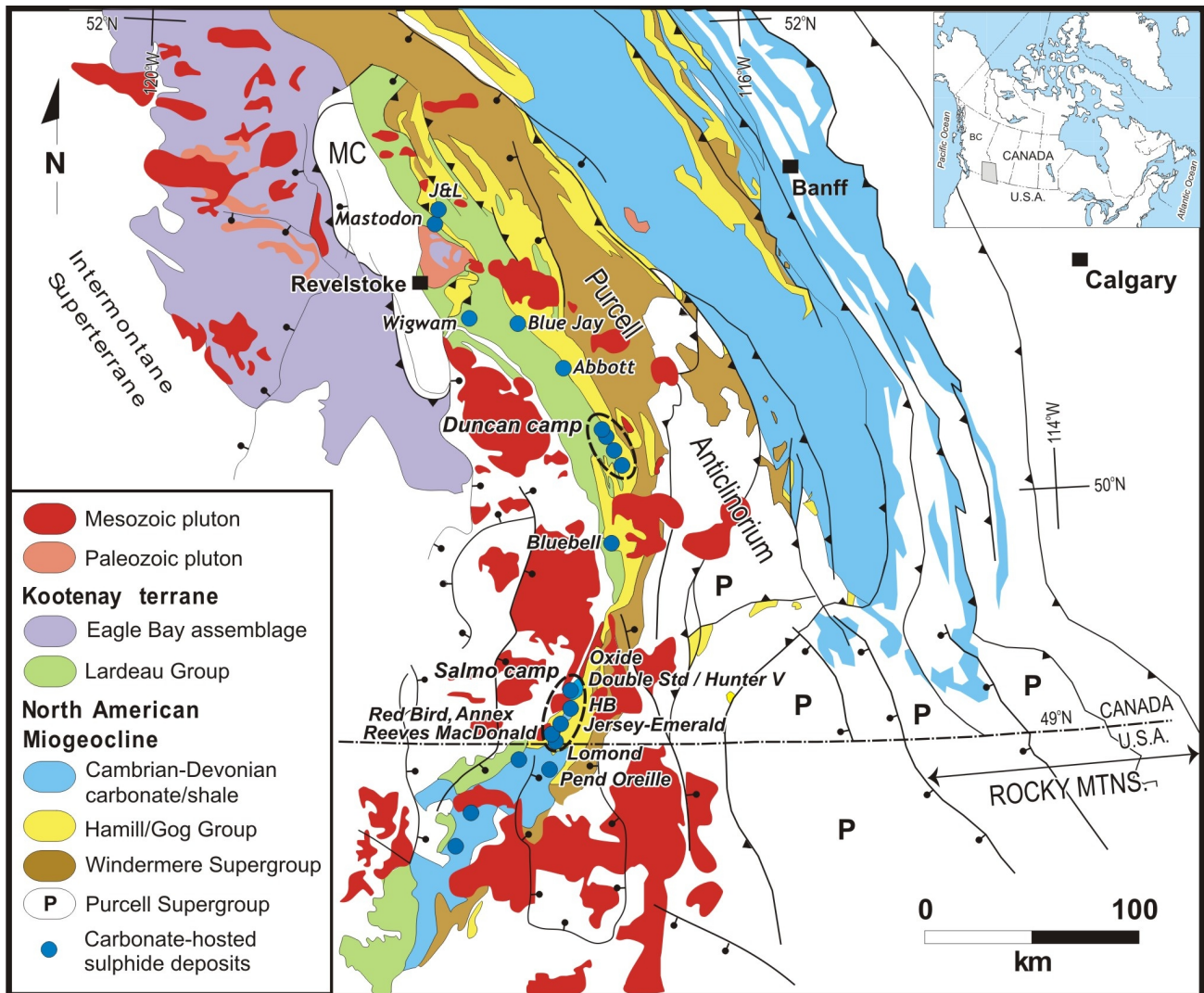
The Kootenay Arc is an arcuate belt of complexly deformed rocks extending at least 400 km from near Revelstoke to the southwest across the Canada–United States border (Fyles, 1964). The Kootenay Arc lies between the Purcell Anticlinorium in the Purcell Mountains to the east and the Monashee metamorphic complex to the west, and it is part of the Kootenay terrane (Figure 2). The arc consists of a thick succession of thrust-imbricated Proterozoic to Early Mesozoic miogeoclinal to basinal strata of sedimentary and volcanic protoliths (Brown et al., 1981). Colpron and Price (1995) outlined a regionally coherent stratigraphic succession in the Kootenay Arc. The lower part is composed of siliciclastic and carbonate rocks of the

Eocambrian Hamill/Gog Group and Mohican Formation. These are overlain by the archaeocyathid-bearing carbonate rocks of the Early Cambrian Badshot Formation and its equivalent, the Reeves Member of the Laib Formation (Fyles and Eastwood, 1962; Fyles, 1964; Read and Wheeler, 1976), which host a number of Zn-Pb sulphide deposits. The Badshot Formation is characterized by calcitic to dolomitic marble. Schist is locally interlayered with the marble. In the southern part of the Kootenay Arc, the carbonate rocks are overlain by siliciclastic, basinal shale and mafic volcanic rocks of the Early Paleozoic Lardeau Group (Colpron and Price, 1995). Polyphase de-



**Figure 1.** Location of the project area, south-central British Columbia, with respect to other significant carbonate-hosted sulphide and nonsulphide occurrences in the northern cordillera, (modified from Nelson et al., 2002, 2006). Abbreviations: CC, Cache Creek terrane; Q, Quesnel terrane; SMRT, Southern Rocky Mountain Trench.





**Figure 2.** Simplified geological map of southeastern British Columbia and surrounding region, showing the Kootenay Arc and location of carbonate-hosted Zn-Pb deposits (modified from Wheeler and McFeely, 1991; Logan and Colpron, 2006; Paradis, 2007). The Cambrian-Devonian carbonates include the Early Cambrian Badshot Formation and its equivalent, the Reeves Member of the Laib Formation, which hosts the Zn-Pb sulphide and nonsulphide deposits. Abbreviations: MC, Monashee complex.

formation has transposed bedding and locally obscured primary stratigraphic relationships (Colpron and Price, 1995).

The Quesnel Lake area in central BC is composed of rocks of the Cariboo terrane, North American miogeocline and the Barkerville subterrane (Figures 2 and 3). To the east, the Cariboo terrane is in fault contact with the western margin of the North American miogeocline along the Rocky Mountain Trench. To the west, it is in fault contact (along the westerly verging Pleasant Valley thrust) with rocks of the Barkerville subterrane, which represent a northern extension of the Kootenay terrane.

The Cariboo terrane comprises thick sequences of Precambrian to Early Mesozoic siliciclastic and carbonate rocks that show similarities with rocks of the North American miogeocline. In the Quesnel Lake area, the Cariboo terrane

is represented by the Late Proterozoic Kaza Group, the Late Proterozoic to Late Cambrian Cariboo Group and the Ordovician to Mississippian Black Stuart Group (Figure 3). The Cariboo Group includes argillite, slate and phyllite of the Isaac Formation; carbonate of the Cunningham Formation; argillite and phyllite of the Yankee Belle Formation; white quartzite of the Yanks Peak Formation; shale, phyllite and micaceous quartzite of the Midas Formation; carbonate of the Mural Formation; and slate, phyllite and minor limestone of the Dome Creek Formation (Struik, 1988). Sedimentary rocks of the Isaac, Cunningham and Yankee Belle formations correlate with those of the Windermere Supergroup, and the quartzite of the Yanks Peak Formation correlates with that of the Hamill Group in southern BC (Struik, 1988). The archaeocyathid-bearing carbonate of the Mural Formation is biostratigraphically correlative with the Badshot Formation of the Kootenay Arc, which

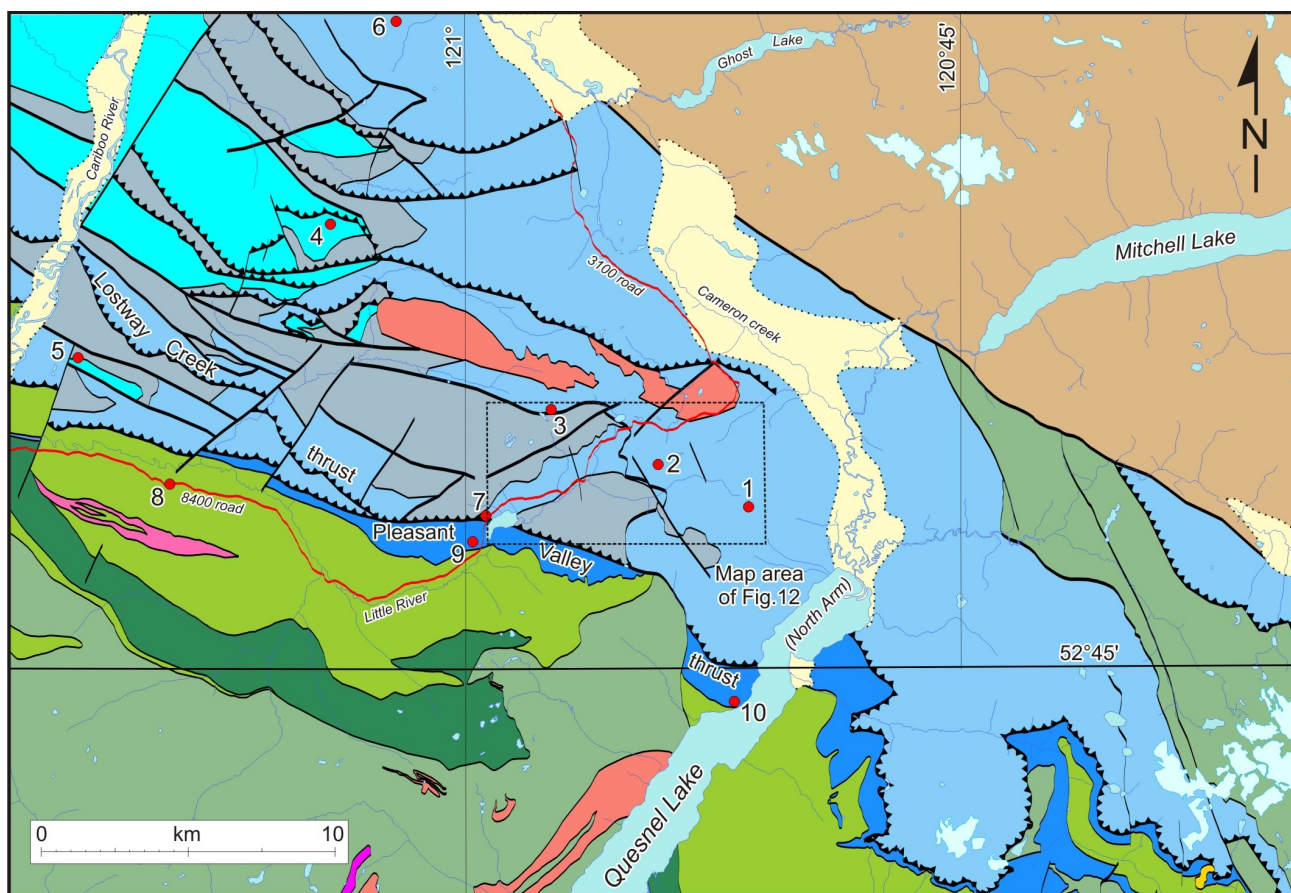
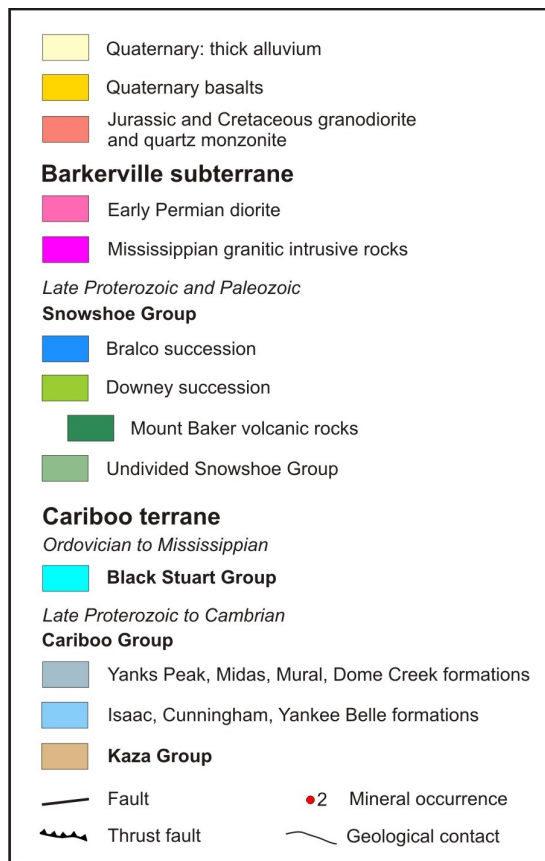


Figure 3. General bedrock geology between the Cariboo River and Mitchell Lake (after Campbell, 1978; Struik, 1983a, b, 1988; Ferri and O'Brien, 2003), east-central British Columbia. The dotted rectangle (occurrences 1, 2 and 3) is the area covered by the Cariboo Zinc property (Figure 12). Mineral occurrences, according to BC MINFILE (BC Geological Survey, 2010): 1, Sil; 2, Grizzly Lake; 3, Lam; 4, Comin Throu Bear; 5, Maybe; 6, Mt. Kimball; 7, Maeford Lake; 8, Ace; 9, Mae; 10, Cariboo Scheelite.

hosts numerous stratabound carbonate-hosted Zn-Pb sulphide and nonsulphide deposits and polymetallic Pb-Zn ( $\pm$ Ag) veins (Struik, 1988; Paradis, 2007).

### Carbonate-Hosted Sulphide and Nonsulphide Deposits of the Salmo Camp

The sulphide deposits of the Salmo camp are commonly referred to as 'Kootenay Arc-type deposits' (Höy, 1982; Nelson, 1991). Most of the deposits occur in Early Cambrian shallow-water platform carbonates of the Badshot Formation or its equivalent, the Laib Formation (Reeves Member). Some occur in the Middle Cambrian to Early Ordovician Nelway Formation. They have been variously interpreted as metamorphosed Mississippi Valley-type (MVT), sedimentary exhalative-type (SEDEX), and Irish-type Pb-Zn deposits (Sangster, 1970, 1990; Nelson, 1991; Goodfellow and Lydon, 2007; Paradis, 2007, 2008). More recently, Paradis (2010) interpreted them as Mississippi Valley-type based on Re-Os dating on the mineralization.



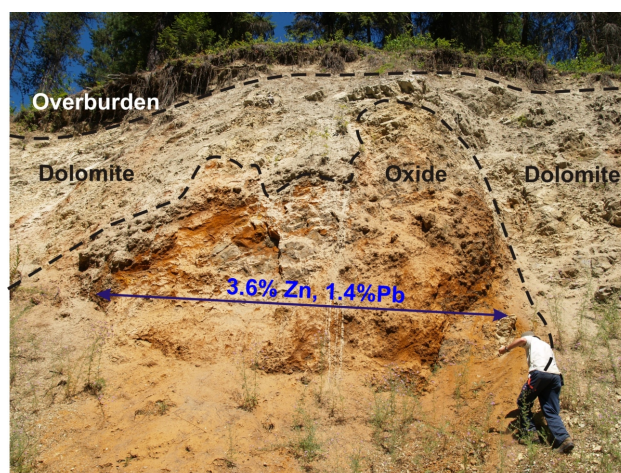


The deposits range in size from 6 to 10 million tonnes with average grades of 3–4% Zn, 1–2% Pb, 0.4% Cd and traces of Ag (Höy, 1982; Höy and Brown, 2000). They are stratabound and stratiform lens-shaped concentrations of sulphides (sphalerite, galena, pyrite, local pyrrhotite and rare arsenopyrite) in isoclinally folded dolomitized or silicified carbonate layers (Paradis, 2007). Several deposits are past-producers (e.g., Reeves MacDonald, Jersey, HB) and others have seen advanced exploration work (e.g., Aspen, Jackpot), although none are presently in production.

With the exception of Lomond (which is hosted by the Middle Cambrian–Early Ordovician Nelway Formation), the deposits are hosted by fine-grained, poorly layered or massive dolostone of the Reeves Member, which is texturally distinct from barren, generally medium-grained, well-banded, grey and white or black and white limestone of the same unit. The mineralized dolostone is dark grey, poorly layered and mottled with black flecks, wisps and layers of impurities (Fyles, 1970). The deposits, their dolostone envelopes, and the limestone host rock generally lie within secondary isoclinal folds along the limbs of regional anticlinal structures. They form stratabound and stratiform, tabular and lens-shaped concentrations of pyrite, sphalerite and galena in dolomitized zones. Brecciated zones are common within the more massive sulphide mineralization (Fyles and Hewlett, 1959; Legun, 2000).

The near-surface portions of the several carbonate-hosted sulphide deposits are weathered, strongly oxidized and consist, in many cases, of extensive Zn- and Pb-bearing, iron-oxide gossans and base-metal-bearing nonsulphide minerals. The weathered zones of some of the deposits are partially delimited and none have been exploited in the past. The mineralogy and paragenesis of oxidized zones are indicative of direct-replacement of sulphides by nonsulphide base-metal-bearing minerals. The main exposure at Lomond is an excellent example of a CHNSBM iron-rich gossan (Figure 4). The Oxide deposit may correspond to the hemimorphite portion of a CHNSBM deposit formed by wallrock-replacement (Figure 5). There are not enough data available to determine conclusively if the Oxide deposit is of the direct- or wallrock-replacement-type, but the dominance of hemimorphite is linked to high silica activity (provided by the underlying Reno Formation quartzite) during base-metal trapping. In most other occurrences, spatial continuity and/or the close spatial relationships, in combination with morphological similarities between sulphide and associated nonsulphide zones, suggest direct-replacement CHNSBM mineralization. The evidence for direct-replacement origin is strongest where the transition of nonsulphide to sulphide mineralization with increasing depth is well documented.

Brief descriptions of sampled deposits are given below; more detailed descriptions can be found in Simandl and



**Figure 4.** The main exposure at the Lomond deposit; an example of a CHNSBM deposit with an iron-rich gossan component, south-eastern British Columbia.



**Figure 5.** Hemimorphite-bearing material, Oxide deposit, south-eastern British Columbia.

Paradis (2009). The descriptions are based on our field investigations (2008, 2009) and descriptions of Fyles and Hewlett (1959), Fyles (1964, 1970), Höy (1982) and Legun (2000).

### Reeves MacDonald, Annex and Red Bird

The Reeves MacDonald deposits are located 30 km south-southwest of the village of Salmo. They include the past-producing deposits of Reeves MacDonald (MINFILE 082FSW026; BC Geological Survey, 2010) and Annex (MINFILE 082FSW219), and the Red Bird prospect (MINFILE 082FSW024). Combined production from 1949 to 1971 totalled 5 848 021 t of sulphide ore grading 3.50% Zn and 1.39% Pb. Like most carbonate-hosted Zn-Pb deposits in the southern Kootenay Arc, the mineralized zones are enclosed by a dolomitized envelope within the Reeves Member limestone. The sulphide orebodies, their enveloping dolostone, and the limestone host rock are



folded and metamorphosed to greenschist facies. Structure in the area is characterized by nearly east-striking foliation and southwesterly trending fold axes. A series of north-striking faults that dip 25–45°E offset the formations and the mineralized zones.

The Reeves MacDonald mine consisted of the Reeves, B.L. (MINFILE 082FSW026) and O'Donnell (MINFILE 082FSW028) deposits, which are interpreted as faulted segments of the same orebody (Fyles and Hewlett, 1959; Gorzynski, 2001). Other deposits in the area, such as Red Bird, Annex, MacDonald (MINFILE 082FSW026), Point (MINFILE 082FSW027) and Prospect (MINFILE 082FSW029) may be related by the style of faulting to the above mineralized zones; however, they may be separate deposits (Fyles and Hewlett, 1959; G. Klein, pers. comm., 2007).

The sulphide bodies are structurally conformable and stratabound. The sulphides form bands, lenses and layers of massive to disseminated material, parallel to compositional layering within medium to dark grey dolostone. Layering varies from millimetre-scale to several centimetres in thickness, and is either continuous over tens of metres, or discontinuous and highly contorted. Lenses of unmineralized light grey dolomite interlayered with thin bands of argillite are common within the ore zones. Sulphides also form a matrix to breccias, which consist of rounded to platy fragments of dolomite, limestone and quartz. The sulphides consist of fine- to medium-grained pyrite, honey-coloured to brown sphalerite, minor galena and traces of chalcopyrite. Copper and cadmium content is typically less than 0.5% and 1 g/t, respectively (S. Paradis, unpublished data, 2010).

Only sulphide mineralization was mined at the Reeves Macdonald and Annex deposit, the nonsulphide base-metal-bearing zones, consisting of earthy yellow-brown gossan of limonite, hematite and goethite, with variable amounts of hemimorphite, cerussite and possibly smithsonite, were left behind. According to Höy et al. (1993), the oxidation occurred prior to glaciation and much of the oxidized material was removed by the advancing ice.

The deposits and prospects (i.e., Reeves MacDonald, Annex and Red Bird) are exposed over a distance of approximately 4 km.

### Red Bird

The Red Bird prospect lies south and west of the Pend Oreille River along Red Bird Creek. It includes zones A, B, C and D described below. The main workings include four adits, a shaft and several more recent trenches and roadcuts. All the underground workings are inaccessible. The indicated resource (which predates National Instrument [NI] 43-101) within the Red Bird prospect is reported at

2 177 040 t grading 18.5% Zn, 6.5% Pb and 68.5 g/t Ag (Price, 1987).

Zone A corresponds to a roadcut of the old Red Bird no. 4 tunnel. The trenches exposed narrow zones of zinc-oxide mineralization in dolostone of the Reeves Member. Gorzynski (2001) reported values of 5.4% Zn over 1.6 m, 6.42% Zn over 1.3 m and 16.1% Zn over 1.5 m.

Zone B, also called the Beer Bottle zone, is located approximately 300 m east of zone A (Figure 6) and has been traced over a strike length of 110 m. It is truncated to the east by the Beer Bottle creek fault and remains open to the west (Klein, 1999; Gorzynski, 2001). Trench B-2000-01 exposed bands and layers of red-brown iron-oxide gossan intercalated with variably altered and weakly mineralized dolomitic limestone (Figure 7). Our assay results from samples selected along trench B-2000-01 are given in Figure 7. Two grab samples from the thickest part of the iron-oxide gossan returned highly variable values of 0.5% and 23% Zn, and 0.12% and 2.8% Pb, respectively. Another sample (no. 181, Table 1) from an iron-oxide-rich band 0.5 m wide returned 15.7% Zn and 3.0% Pb. Samples of the weakly mineralized dolomitic limestone also returned interesting Zn and Pb values (see Figure 7). In 2000, Redhawk Resources Inc. analyzed a channel sample across the section, which returned 15.00% Zn over 12.8 m (Gorzynski, 2001). The footwall portion of this zone assayed 22.16% Zn over 6.3 m, and the hangingwall portion returned 8.08% Zn over 6.5 m (Gorzynski, 2001).

Zone C, located 150 m northeast of Zone B (Figure 6), is one of the main mineralized zones of the Red Bird prospect exposed at surface. It is interpreted as a down-faulted portion of zone B. Red Bird tunnel no. 1 exposed a nonsulphide section of approximately 140 m in length, including a 75 m long and over 6 m wide zone that has average grades of 18.55% Zn, 5.97% Pb and 36.7 g/t Ag (Emendorf, 1927; Sorensen, 1942; Gorzynski, 2001). One of the re-excavated road cuts (approximately 100 m in length; Figure 8), located 85 m in elevation above tunnel no. 1, exposed a nonsulphide-rich section that returned 6.93% Zn over 21 m (Gorzynski, 2001). High-grade zones in the footwall and hangingwall of this section assayed 12.30% Zn over 4.4 m and 9.75% Zn over 5.6 m (Gorzynski, 2001). Assay results of samples collected in 2009 along trench C-2000-01 are given in Figure 8. This section exposes high-grade iron-oxide gossan, which replaced the weakly mineralized dolostone. Two smaller bands of iron-oxide gossan are present in the argillaceous limestone or at the contact between the altered dolostone and the limestone. One sample at the contact zone assayed 43.7% Zn and 0.68% Pb.

Zone D was found by deep drilling. One drillhole reported an oxidized intersection of 16.7 m that assayed 7.2% Pb, 8.95% Zn and 23.5 g/t Ag, directly overlying a 1.5 m sul-

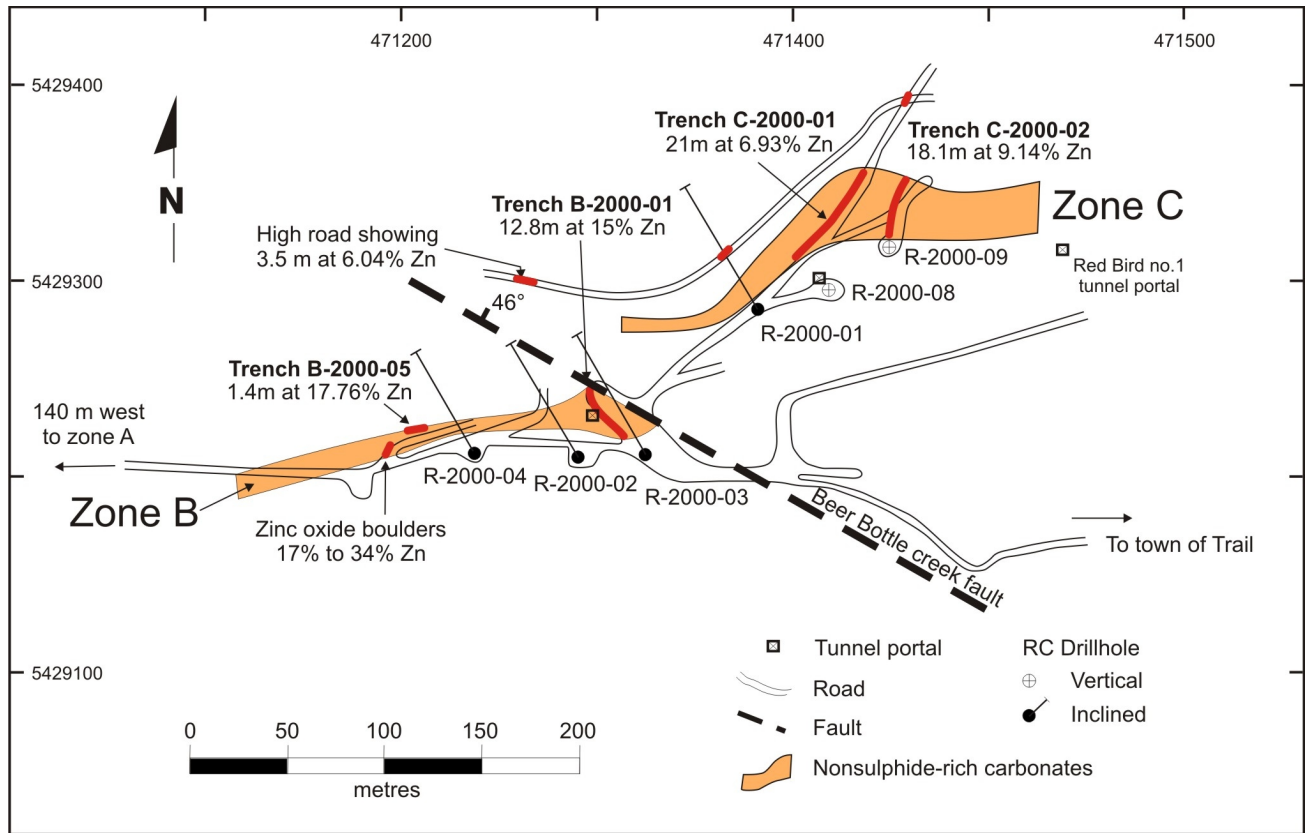


Figure 6. Schematic surface plan of zones B and C, Red Bird prospect, southeastern British Columbia (after Gorzynski, 2001).

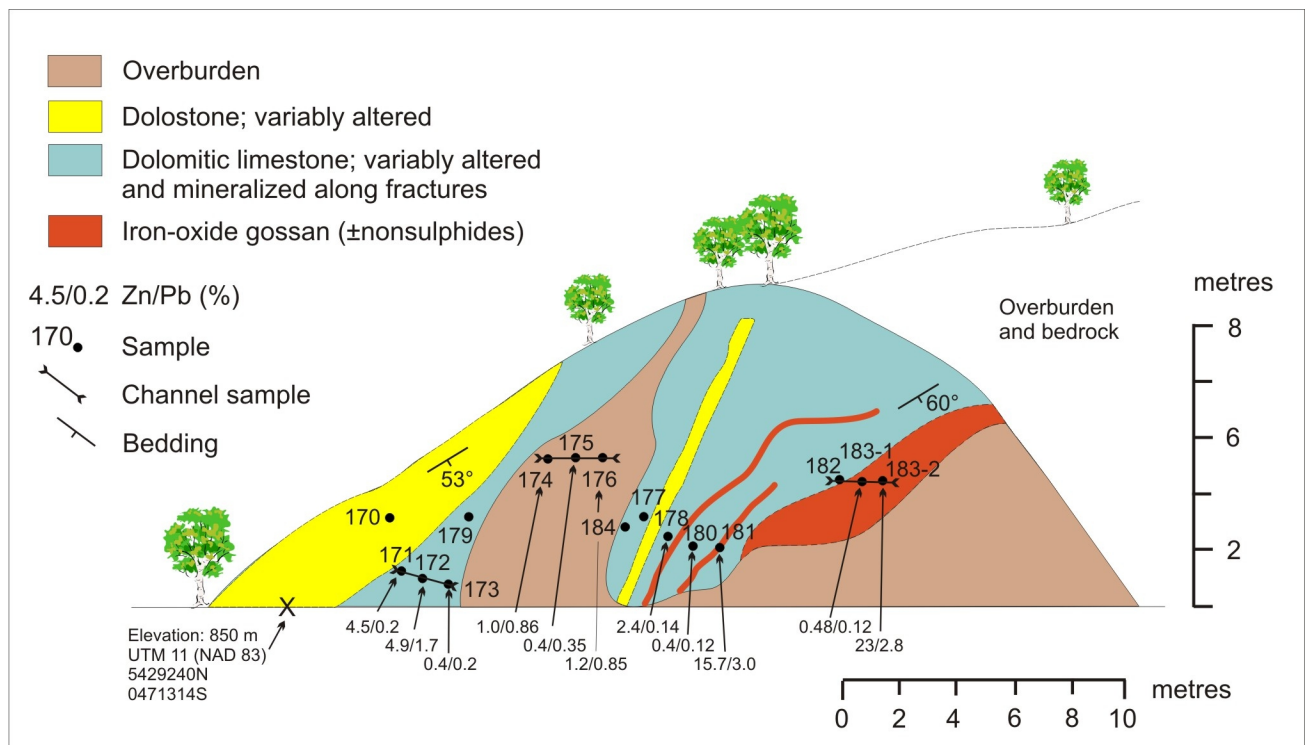


Figure 7. Vertical section oriented 316°, looking northeast of trench B-2000-01, Red Bird prospect, southeastern British Columbia.

**Table 1.** Chemical analyses of selected nonsulphide-rich samples from the Salmo district and Cariboo Zinc property, southeastern British Columbia.

Sample no.	Deposit	Location <sup>1</sup>	Rock type	Element:													Total C %	Total S %	Cu ppm	Mo ppm	As ppm	Ba ppm	Co ppm	Ni ppm				
				Zn	Pb	Fe	Mn	Ca	P	Mg	Al	Cd	Ag	Au	ICP-ES	ARMS									Leco	ARMS	ICP-MS	ARMS
				%	%	%	%	%	%	%	%	%	g/t	ppb	%	%									ppm	ppm	ppm	ppm
				0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.001	2	0.5	0.02	0.02	0.1	0.1	0.5	1	0.2	0.1						
07-SP-19-1	Red Bird	5429240N 471308E	Iron-oxide gossan	4.22	4.12	47.05	0.01	0.23	0.42	0.07	0.15	0.024	4	51.4	0.26	0.05	68.9	29.1	269.3	127	7.4	258						
07-SP-19-2	Red Bird	5429240N 471308E	Altered dolostone	0.13	<0.02	0.28	0.03	21.7	<0.01	11.21	0.09	0.004	<2	2.1	13.57	0.03	1.3	0.2	4.9	395	0.2	4.3						
07-SP-20-2	Red Bird	5429349N 471420E	Iron-oxide gossan	3.64	3.67	48.23	<0.01	0.18	0.56	0.06	0.13	0.018	3	12	0.19	0.13	50.6	7.4	215.2	93	0.7	105.2						
08-SP-85	Oxide	5457482N 489475E	Nonsulphide-rich carbonate	38.77	0.13	0.72	0.06	3.21	9.8	0.09	0.42	0.23	32	1.2	0.12	<0.02	1.8	<0.1	10.3	130	0.7	330						
08-SP-87A	Oxide	5457719N 489516E	Nonsulphide-rich carbonate	49.79	0.19	3.29	0.1	0.05	6.17	0.03	0.04	0.042	7	12.9	0.04	<0.02	2.2	0.1	12.4	20	0.8	114.9						
08-SP-87B	Oxide	5457719N 489516E	Iron-oxide gossan	1.55	1.02	56.19	<0.01	<0.01	0.22	0.07	0.01	0.005	4	11.2	0.66	<0.02	3.1	5.3	23.6	16	0.8	20.1						
08-SP-88B	Oxide	5457365N 489966E	Nonsulphide-rich carbonate	31.52	0.14	1.53	0.06	0.12	0.14	0.19	1.47	0.008	4	21.2	0.05	0.04	5.5	0.1	35.1	258	6	426.5						
08-SP-104A	Jersey	5439662N 483892E	Iron-oxide gossan	4.46	1.14	41.06	0.03	2.02	0.02	0.7	0.07	0.024	16	6.2	0.97	29	238.2	29.4	10.6	26	0.3	91.5						
08-SP-104B2	Jersey	5439685N 483918E	Iron-oxide gossan	4.18	1.28	39.41	0.01	1.37	0.01	0.26	0.05	0.022	20	15.6	0.31	40.04	228.7	13.4	75.7	11	45.4	78.4						
08-SP-105	Jersey	5439963N 484104E	Iron-oxide gossan	0.8	3.08	49.37	<0.01	0.12	0.02	0.08	0.16	0.003	3	53.1	4.64	0.68	29.3	101.5	60.5	9	1.5	27						
08-SP-112	Jersey	5439836N 484182E	Oxidized, mineralized dolostone	29.07	11.61	3.16	0.04	4.82	0.08	2.72	0.15	0.342	25	43.6	9.39	<0.02	174.6	10.3	91.7	72	9.5	3.7						
08-SP-113	Jersey	5439830N 484168E	Oxidized, mineralized dolostone	36.83	7.71	9.41	0.03	1.24	0.13	0.71	0.13	0.177	24	33.6	4.98	0.03	62.4	15.2	184.3	184	6.6	10.4						
08-SP-114	Jersey	5439777N 484107E	Oxidized, mineralized dolostone	8.64	8.17	1.83	0.03	15.52	0.02	8.95	0.07	0.067	47	46	10.27	4.87	7.9	2.7	14.3	38	2.2	2.3						
08-GS-15	HB	5444589N 485465E	Iron-oxide gossan	30.63	5.09	19.34	0.07	0.28	0.06	0.46	0.07	0.133	98	154.4	0.63	0.02	17.3	11	100.8	62	13.7	27.3						
08-GS-16	Lomond	5427797N 475327E	Iron-oxide gossan	2.2	1.17	32.87	0.33	10.32	0.17	1.91	0.38	0.001	2	3.7	4.56	0.02	13.5	2.8	171	73	2.2	51.9						
08-GS-16A	Lomond	5427797N 475327E	Iron-oxide gossan	1.85	1.23	52.8	0.02	0.65	0.17	0.19	0.19	0.001	<2	5.8	0.36	<0.02	10.1	2.3	237.4	23	0.5	49.2						
08-GS-17	Lomond	5427797N 475327E	Iron-oxide gossan	1.53	0.77	56.45	<0.01	0.05	0.11	0.03	0.04	<0.001	<2	3.9	0.14	0.06	12.1	2	125.2	4	0.3	32.2						
08-GS-18A	Lomond	5427785N 475301E	Iron-oxide gossan	3.57	1.41	48.94	0.05	0.62	0.26	0.35	0.21	0.002	<2	3	0.42	0.02	25.5	4.1	281.2	38	1.3	57.3						
08-GS-18B	Lomond	5427785N 475301E	Iron-oxide gossan	3.4	1.37	49.32	0.04	0.52	0.24	0.3	0.17	0.001	<2	2.5	0.38	0.02	18.9	3.5	236.7	27	1	48.8						
08-GS-18C	Lomond	5427785N 475301E	Altered dolostone	0.36	0.13	4.44	0.06	19.14	0.03	11.51	0.07	<0.001	<2	<0.5	12.19	0.05	5.7	0.5	23.3	11	0.7	7						
08-GS-19A	Lomond	5427915N 475482E	Iron-oxide gossan	1.23	0.66	53.8	0.01	0.76	0.19	0.47	0.13	0.001	<2	3.7	0.51	0.03	30.2	1.4	241.5	18	0.6	26.6						
08-GS-20A	Lomond	5427906N 475494E	Iron-oxide gossan	2.42	1.41	53.33	<0.01	0.13	0.16	0.1	0.2	0.002	3	6.2	0.17	<0.02	44.4	3.1	141.7	25	1.6	60.4						
08-GS-21	Lomond	5427910N 475526E	Iron-oxide gossan	2.25	0.94	53.41	<0.01	0.13	0.13	0.09	0.05	0.001	<2	6.4	0.19	0.02	30.6	3.3	350.5	9	4.8	103						



Table 1 (continued)

Sample no.	Deposit	Location <sup>1</sup>	Rock type	Element:																		
				Zn	Pb	Fe	Mn	Ca	P	Mg	Al	Cd	Ag	Au	Total C	Total S	Cu	Mo	As	Ba	Co	Ni
				Units: %	%	%	%	%	%	%	%	%	g/t	ppb	%	%	ppm	ppm	ppm	ppm	ppm	ppm
Detection limit:	0.01	0.02	0.01	0.01	0.01	0.01	0.01	0.01	0.01	0.001	2	0.5	0.02	0.02	0.1	0.1	0.5	1	0.2	0.1		
				ICP-ES										ARMS	Leco	ARMS			ICP-MS	ARMS		
08-GS-22D	Lomond	5427787N 475355E	Iron-oxide gossan	1.77	2.47	55.45	<0.01	0.08	0.09	0.03	0.05	<0.001	<2	5.1	0.2	0.04	20.8	1.6	158.3	7	0.8	31.8
09-SP-172	Red Bird, Trench B 2000-01	5429240N 471314E	Oxidized clay	4.9	1.65	41.28	0.25	0.73	0.54	0.36	0.68	0.038	2	2.1	0.24	<0.02	39.7	32	206.4	325	16.1	423
09-SP-174	Red Bird, Trench B 2000-01	5429240N 471314E	Nonsulphide-rich dolostone	1.03	0.76	13.55	0.06	15.91	0.18	0.32	0.25	0.185	<2	0.7	5.06	<0.02	15.3	16.8	77.6	126	11.7	221.6
09-SP-176	Red Bird, Trench B 2000-01	5429240N 471314E	Iron-oxide gossan	1.21	0.85	51.09	0.03	0.24	0.2	0.06	0.16	0.031	<2	4.1	0.11	0.04	11.5	3.9	43.7	84	6.9	200
09-SP-181	Red Bird, Trench B 2000-01	5429240N 471314E	Iron-oxide gossan	15.73	2.99	33.07	0.06	1.03	0.43	0.57	0.58	0.034	17	44.7	0.63	0.03	71.4	13.6	149.8	1007	13.4	292.4
09-SP-183-1	Red Bird, Trench B 2000-01	5429240N 471314E	Iron-oxide gossan	23.04	2.82	28.14	0.03	0.58	0.29	0.34	0.58	0.022	49	127.4	0.41	0.04	78.4	11.9	131.9	518	11.1	238.7
09-SP-186	Red Bird, Trench C 2000-01	5429388N 471447E	Iron-oxide gossan	4.05	2.26	44.05	0.14	1.86	0.28	0.23	0.5	0.019	5	8.1	0.91	0.02	45.2	13	128.7	233	3.5	84.3
09-SP-191	Red Bird, Trench C 2000-01	5429388N 471447E	Nonsulphide-rich dolostone	43.7	0.68	4.75	0.01	1.93	0.12	1.12	0.16	0.019	89	13.8	1.22	0.04	52.8	2.9	31.8	382	6	20.3
09-SP-195	Red Bird, Trench C 2000-01	5429388N 471447E	Iron-oxide gossan	7.76	3.95	42.42	0.01	0.42	0.54	0.19	0.05	0.021	7	6	0.33	<0.02	36.6	14.9	152.2	60	5.6	223.6
09-SP-197	Red Bird, Trench C 2000-01	5429388N 471447E	Iron-oxide gossan	3.14	3.57	49.36	<0.01	0.21	0.44	0.05	0.07	0.021	3	27.7	0.42	0.1	34.3	43.4	249.1	17	3	88.1
09-SP-198	Red Bird, Trench C 2000-01	5429388N 471447E	Iron-oxide gossan	2.51	2.77	50.99	<0.01	0.13	0.33	0.05	<0.01	0.016	4	41.8	0.32	0.06	29.6	33.4	266.4	17	5.5	121.5
09-SP-200	Red Bird, Trench C 2000-01	5429388N 471447E	Iron-oxide gossan	1.29	1.63	53.1	<0.01	0.44	0.15	0.13	<0.01	0.016	8	11.6	0.86	0.06	41.2	19.7	159.4	39	6.5	82
09-SP-204	Red Bird, Trench C 2000-01	5429388N 471447E	Nonsulphide-rich dolostone	15.03	0.69	2	0.02	26.11	0.09	2.26	0.09	0.108	22	6.9	9.1	<0.02	21.8	0.8	12.6	166	5.6	17.6
09-SP-207	Red Bird, Trench C 2000-02	5429335N 471450E	Iron-oxide gossan	11.9	5.09	39.6	0.01	0.55	0.49	0.19	0.1	0.017	24	8.5	0.55	0.06	60.9	34.6	268.3	131	4.4	84.2
09-SP-220B	Cariboo Zinc, Dolomite Flats	5853965N 641517E	Mineralized dolostone	0.25	0.08	0.18	0.05	20.38	0.01	12.1	0.07	0.001	<2	<0.5	12.81	<0.02	1.1	<0.1	5.5	35	0.3	1.3
09-SP-221	Cariboo Zinc, Dolomite Flats	5853951N 641596E	Mineralized dolostone	5.6	<0.02	0.34	0.11	18.48	0.02	10.78	0.02	0.018	<2	<0.5	12.84	0.02	7.5	<0.1	5.5	9	3	1.1
09-SP-225F	Cariboo Zinc, Main Zone	5853400N 641939E	Quartz-galena-bearing vein	5.56	42.97	0.78	0.05	5.73	<0.01	3.21	0.13	0.026	57	3.9	4.75	5.69	46.2	1.9	2	22	2.6	2.6
09-SP-231B	Cariboo Zinc, Gunn zone	5852188N 643413E	Mineralized dolostone	0.8	0.29	0.11	0.03	17.3	<0.01	10.26	<0.01	0.002	<2	<0.5	10.64	<0.02	1.5	<0.1	<0.02	13	0.2	0.4
09-SP-237A	Cariboo Zinc, Que zone	5851520N 644120E	Nonsulphides	51.03	0.14	0.43	0.03	0.13	0.02	0.06	0.04	0.023	3	13.3	0.18	0.6	86.9	0.6	30.9	80	1.5	0.5
09-SP-242	Cariboo Zinc, Que zone	5851843N 643242E	Nonsulphides	43.32	0.94	0.67	0.03	2.32	0.05	1.3	0.19	0.111	2	3.2	4.65	0.14	65	1.1	8.3	725	1.4	0.4
09-SP-243	Cariboo Zinc, Que zone	5851843N 643242E	Nonsulphides	17.32	1.48	0.76	0.05	8.25	0.05	4.68	0.76	0.054	<2	1.6	8.45	0.13	59.9	0.4	3.8	34	2.2	2.7

Abbreviations: ICP-ES, inductively coupled plasma–emission spectrometry; ICP-MS, inductively coupled plasma–mass spectrometry; ARMS, aqua-regia digestion followed by inductively coupled plasma–mass spectrometry; Total S, total sulphur; Total C, total carbon

<sup>1</sup>Coordinates are given in Universal Transverse Mercator (UTM) projection, North American Datum 1983.

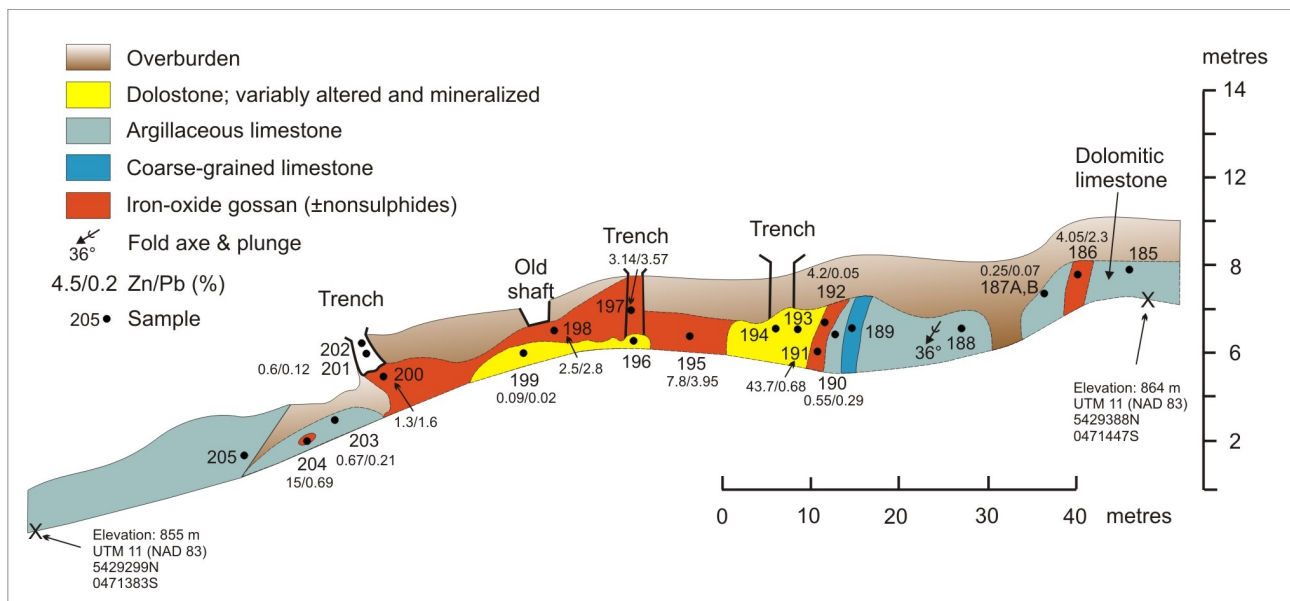


Figure 8. Vertical section oriented 030°, looking northwest of trench C-2000-01, Red Bird prospect, southeastern British Columbia.

phide-rich dolomite section that assayed 5.64% Zn, 0.38% Pb, 8.8 g/t Ag and 0.06% Cd (Price, 1987).

### Lomond

The Lomond occurrence (MINFILE 082FSW018) is located approximately 27 km south of Salmo, BC. Highly oxidized Pb-Zn sulphides are exposed within the middle and upper part of the Middle Cambrian to Early Ordovician Nelway Formation, which consists of cream- and grey-banded dolomite with discontinuous lenses of darker dolostone and dolomitic siltstone (Fyles and Hewlett, 1959). The main showing (Figure 4) is predominantly iron oxides (limonite and goethite). It was mined between 1947 and 1948 as well as in the 1950s, and a small quantity of hand-sorted galena was shipped to the smelter at Trail (BC).

Two oxidized zones, 1.5 and 3.6 m thick and 3 m apart, are described by Fyles and Hewlett (1959) as conformable to the dolomitic banding, but locally discordant. They consist of earthy brown, iron-oxide limonite containing harder areas of goethite. Within the soft earthy limonite are occasional anglesite-coated nodules of galena. Transparent to translucent crystals of cerussite (0.5–2 mm long) are locally present within the open cavities (Figure 9). A sample of the main oxidized zone assayed 10.3 g/t Ag, 1.2% Pb and 2.7% Zn (Fyles and Hewlett, 1959). A 4.8 m long channel sample assayed 3.6% Zn, 1.41% Pb and 48.9% Fe (Figure 4), and various grab samples assayed from 0.4 to 2.4% Zn and 0.13 to 2.5% Pb.

### Jersey-Emerald

The Jersey-Emerald property (MINFILE 082FSW009) lies approximately 11 km southeast of the village of Salmo. It

encompasses the former Jersey and Emerald Zn-Pb mines, and the Emerald, Feeny, Invincible and Dodger tungsten mines. Only the Zn-Pb deposits will be considered in this study. Lead-zinc production of over 8 million tonnes grading 1.95% Pb and 3.83% Zn (Sultan Minerals Inc., 2010) was recorded for the Jersey and Emerald deposits.

The Jersey-Emerald Zn-Pb mineralization occurs within a dolomitized zone, near the base of the Reeves Member. Five Zn-Pb dolomite-hosted ore bands, ranging in thickness from 0.3 to 9 m, are recognized within the mine. Recent drilling intersected a Pb-Zn-bearing dolomite horizon located 55–60 m below the former Jersey Zn-Pb deposit. Sulphide ore consists of fine-grained sphalerite and galena with pyrite and pyrrhotite. The galena-sphalerite-pyrite-

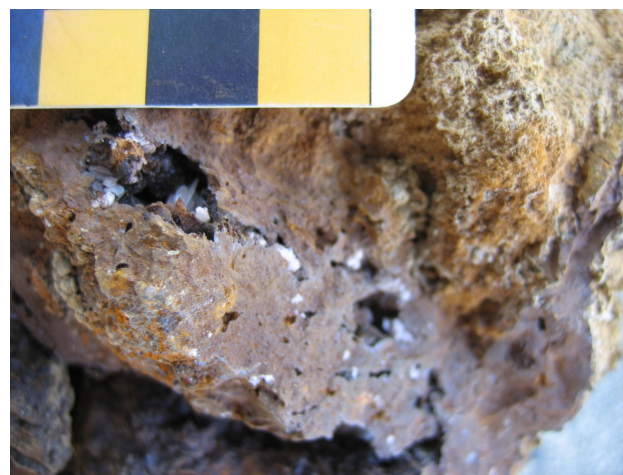


Figure 9. Cerussite crystals in open cavities of a goethite sample, Lomond deposit, southeastern British Columbia.



pyrrhotite ore is banded and similar to ore from the HB deposits, where Pb dominates.

Unlike many of the other carbonate-hosted Pb-Zn deposits in the Salmo area, there is no record of a near-surface oxidation zone at Jersey. Generally, this agrees with the authors' field observations. The mine is dry and only two of the ten ore zones, B and D, were exposed at the surface. Both of these zones are elongated approximately northward and plunge gently south. Only the southern-most and topographically lowest portions of these orebodies outcropped. An iron-rich gossan (Figure 10) was noted and sampled at 1394 m of elevation, west of the Emerald Zn-Pb mine portal no. 1; a grab sample from this zone assayed 3.08% Pb and 0.8% Zn (49.4% Fe).

### HB

The HB mine (MINFILE 082FSW004) is located 8 km southeast of the village of Salmo. It consists of the HB and Garnet deposits. The HB deposit contains at least five orebodies and the Garnet deposit is a single lens. The mine produced a total of 6 656 101 tonnes of ore between 1912 and 1978. Measured and indicated reserves, published in 1978 (predating NI 43-101) by Canadian Pacific Limited, were 36 287 tonnes grading 0.1% Pb and 4.1% Zn (Anonymous, 1983).

The orebodies, hosted by the Reeves Member limestone, are located less than 100 m west of the Argillite fault. Sedimentary rocks in the mine area are folded into a broad synclorium, and the limestone-dolostone beds hosting the orebodies are on the west limb of this structure. The main mineralization at HB consists of three elongated, crudely ellipsoid orebodies dipping steeply toward the east and plunging 15–20° southward. These steeply dipping orebodies are connected by two gently dipping tabular sulphide breccia bodies, which also plunge 15–20° southward (MINFILE 082FSW004). The steeply dipping orebodies



**Figure 10.** Iron-rich gossan on the Jersey-Emerald property, southeastern British Columbia.

consist of concentrations of discontinuous stringers that have a Pb:Zn ratio of 1:5, whereas the tabular brecciated mineralized zones have a Pb:Zn ratio of approximately 1:2.5 (MINFILE 082FSW004). The sulphide concentrations within steeply dipping ore zones appear to be parallel to cleavage in the host dolomitic limestone (MacDonald, 1973). Sulphide mineralization within the tabular zones appears to follow the bedding.

Sulphide minerals consist predominantly of fine-grained pyrite and subordinate sphalerite, galena and locally minor pyrrhotite. The sulphide mineralization is enveloped by a broad zone of dolomitization, which is bordered along its contact with limestone by a narrow silica-rich zone.

The northern portions of the mineralized zones are exposed at surface and oxidized to a depth of 100 m (Fyles and Hewlett, 1959). Available evidence points to the origin by the direct-replacement process. Nonsulphide minerals include hemimorphite  $\{Zn_4Si_2O_7(OH)_2 \cdot H_2O\}$ , cerussite  $\{PbCO_3\}$  and goethite  $\{FeO(OH)\}$ . Fyles and Hewlett (1959) also mentioned the following phosphates: pyromorphite  $\{Pb_5(PO_4)_3Cl\}$ , hopeite  $\{Zn_3(PO_4)_2 \cdot 4H_2O\}$ , spencerite (an uncommon zinc phosphate)  $\{Zn_4(PO_4)_2(OH)_2 \cdot 4H_2O\}$  and tarbuttite  $\{Zn_2(PO_4)(OH)\}$ . A grab sample from the oxidized zone assayed 30.6% Zn, 5.1% Pb and 19.3% Fe.

### Oxide

The main showings of the Oxide prospect (MINFILE 082FSW022) outcrop to the west of the north-striking Oxide pass, 5.5 km east-southeast of Ymir, BC. The area is underlain by black argillite and slate of the Early(?) to Middle Ordovician Active Formation, grey limestone of the Reeves Member of the Laib Formation, and micaceous and white quartzite resembling the lower Nevada Member of the Quartzite Range Formation (Fyles and Hewlett, 1959).

Mineralization is hosted by the Oxide fault, which strikes 010° and dips 75 to 80°E. The fault zone (up to 9 m wide) consists of crushed and sheared rocks, containing a muddy clay-like gouge about 0.5 m thick (Fyles and Hewlett, 1959; MINFILE 082FSW022). The nonsulphide base-metal-bearing zone at the Oxide adit was reported to be highly oxidized and was exposed along strike for 458 m with a maximum width approaching 9 m. Past drilling and underground development confirmed that the oxidized zone extends more than 180 m in depth. The International adit, located approximately 830 m to the south of the Oxide adit, intersects an oxide zone up to 7.3 m in width, which is also reported to host nonsulphide Zn-Pb mineralization.

Figure 5 shows the typical exposure in the vicinity of the Oxide fault. The limonitic gossan contains hemimorphite (Figure 11) and hydrozincite as the major Zn-bearing minerals. Parahopeite, galena nodules and pyromorphite have



also been reported by McAllister (1951). The highest assay from the Oxide adit in 1948 was 15.7% Zn, 1.4% Pb, 0.34 g/t Au and 3.4 g/t Ag (Fyles and Hewlett, 1959). Grab samples from various iron-oxide gossans and base-metal-bearing nonsulphide outcrops assayed from 1.55 to 49.8% Zn, 0.13 to 1.02% Pb, 0.72 to 56.2% Fe and 0.14 to 9.8% P (Table 1).

### Carbonate-Hosted Sulphide and Nonsulphide Deposits of the Cariboo Zinc Property

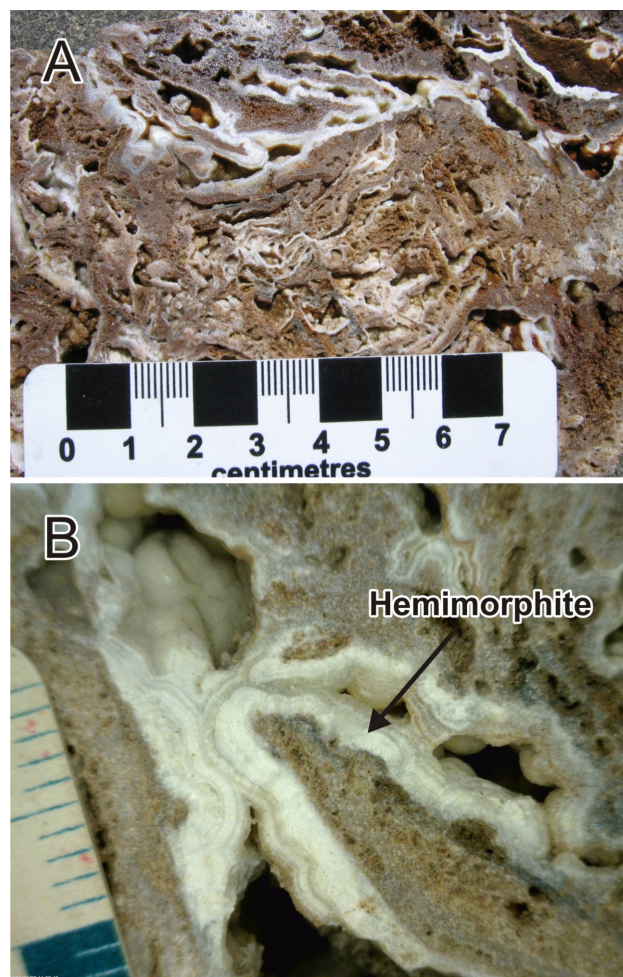
The carbonate-hosted sulphide and nonsulphide occurrences (Flipper Creek, Dolomite Flats, Main, Gunn and Que) of the Cariboo Zinc property (NTS 093A/14E and 15W; Figure 12) belong to a number of stratabound Zn-Pb occurrences in Late Proterozoic to Early Paleozoic platform carbonate units and carbonaceous shale units of the Cariboo terrane, such as Comin Throu Bear (MINFILE 093A 158) and Maybe (MINFILE 093A 110).

The Cariboo Zinc property encompasses several Zn-Pb sulphide and nonsulphide occurrences in a southeast-trending belt about 8 km long. The main occurrences, from west to east, are Canopener, DeBasher, Flipper Creek, Dolomite Flats, Main, Gunn and Que (Figure 12). In the BC MINFILE database, DeBasher corresponds to the LAM showing (MINFILE 093A 050), Flipper Creek, Dolomite Flats, and Main are encompassed by the Grizzly Lake prospect (MINFILE 093A 065), and Gunn and Que correspond to the Sil showing (MINFILE 093A 062).

The Cariboo Zinc property is underlain by folded and interlayered Late Proterozoic carbonate and pelitic metasedimentary rocks of the Cunningham and Isaac formations of the Cariboo Group (Figure 3). The carbonates and interlayered metapelitic sediments strike 240° and dip to the northwest in the northern part of the property, and strike 310° and dip to the northeast in the southern part (Murrell, 1991; McLeod, 1995). This suggests the presence of a major open fold, with a hinge located near the Grizzly Lake area. A strong southwest- to northwest-striking foliation is present in metapelitic units on the eastern limb of the fold. The western limb is characterized by a southwest-striking foliation that generally dips northwest. Several north- to northeast-trending faults are interpreted to cross-cut the metasedimentary rocks (Figure 12).

The sulphide and nonsulphide occurrences are hosted by a dolostone-dolomitic limestone unit adjacent to a 'phyllite' unit of the Cunningham Formation (Paradis et al., 2010).

Brief descriptions of sampled deposits are given below; more detailed descriptions can be found in Paradis et al. (2010). The descriptions are based on field observations (Paradis et al., 2010) and reports of Murrell (1991) and Bradford and Hocking (2008).

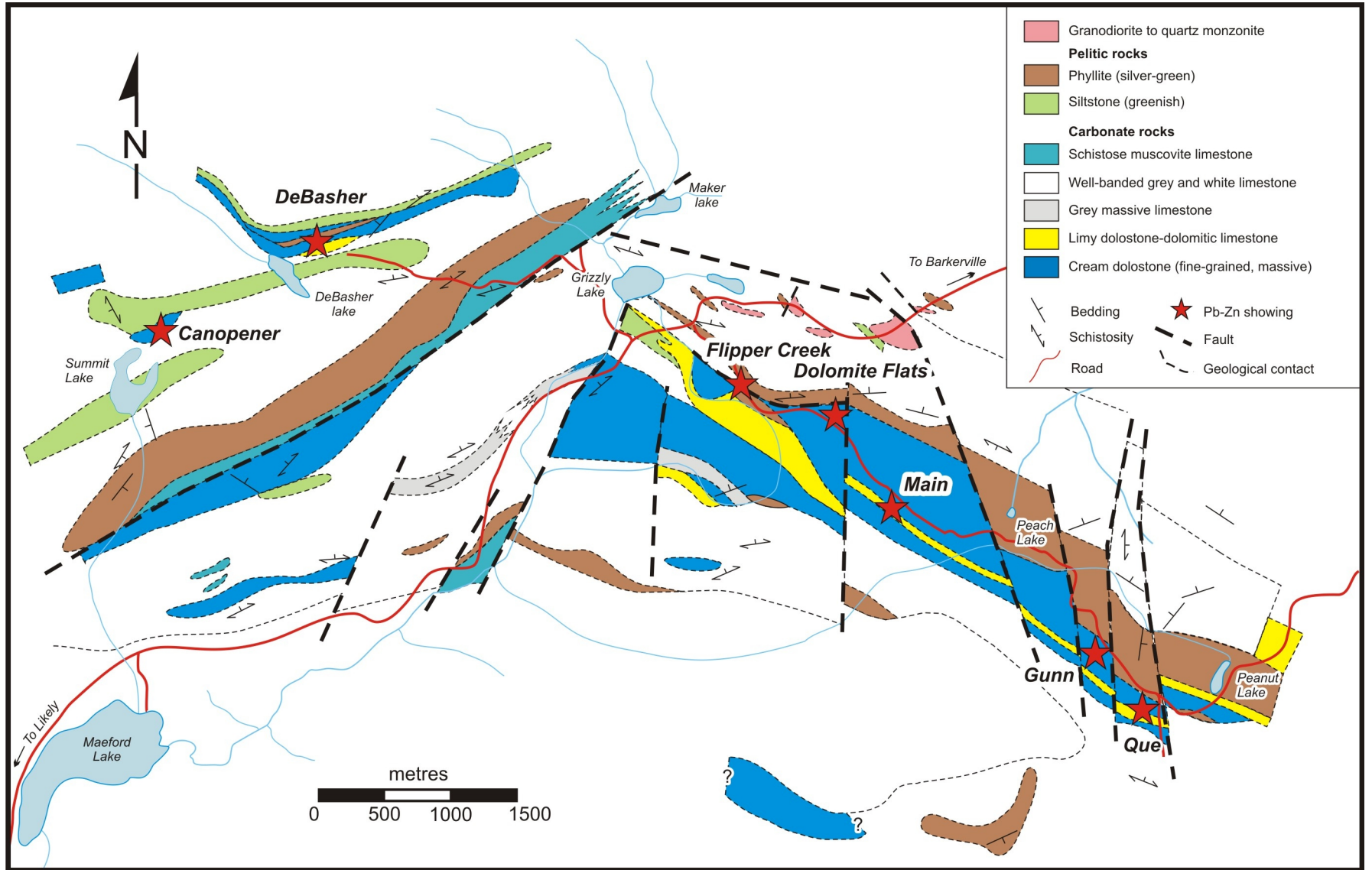


**Figure 11.** Oxide deposit, southeastern British Columbia: **A)** Hemimorphite-rich sample; **B)** Close up of A) showing aggregates of white radiating hemimorphite crystals forming botryoidal structures.

### Flipper Creek

Mineralization of the Flipper Creek prospect, hosted by medium-grained white dolostone, consists of clots and pods of sphalerite, veins, and distinctive breccia zones approximately 0.5 m thick containing barite, galena and sphalerite. The breccia is crosscut by a white, fine- to coarse-grained barite vein trending 185°, which has seams and pods of galena and sphalerite within and along the margin of the vein. Barite-associated mineralization postdates some earlier sphalerite- and galena-bearing veinlets.

According to Murrell (1991), mineralization is preferentially located at the contact between phyllite to the north and underlying cream dolostone to the south. This contact may correspond to a northwest-trending fault along Flipper creek. Murrell (1991) reported patchy green sphalerite, hosted within the cream dolostone and associated with white barite in proximity to the fault. Irregular dissemi-



**Figure 12.** Regional geology of the Cariboo Zinc property area, Quesnel Lake area, east-central British Columbia (from Lormand and Alford, 1990). Lake names with the generic in lower case are unofficial.

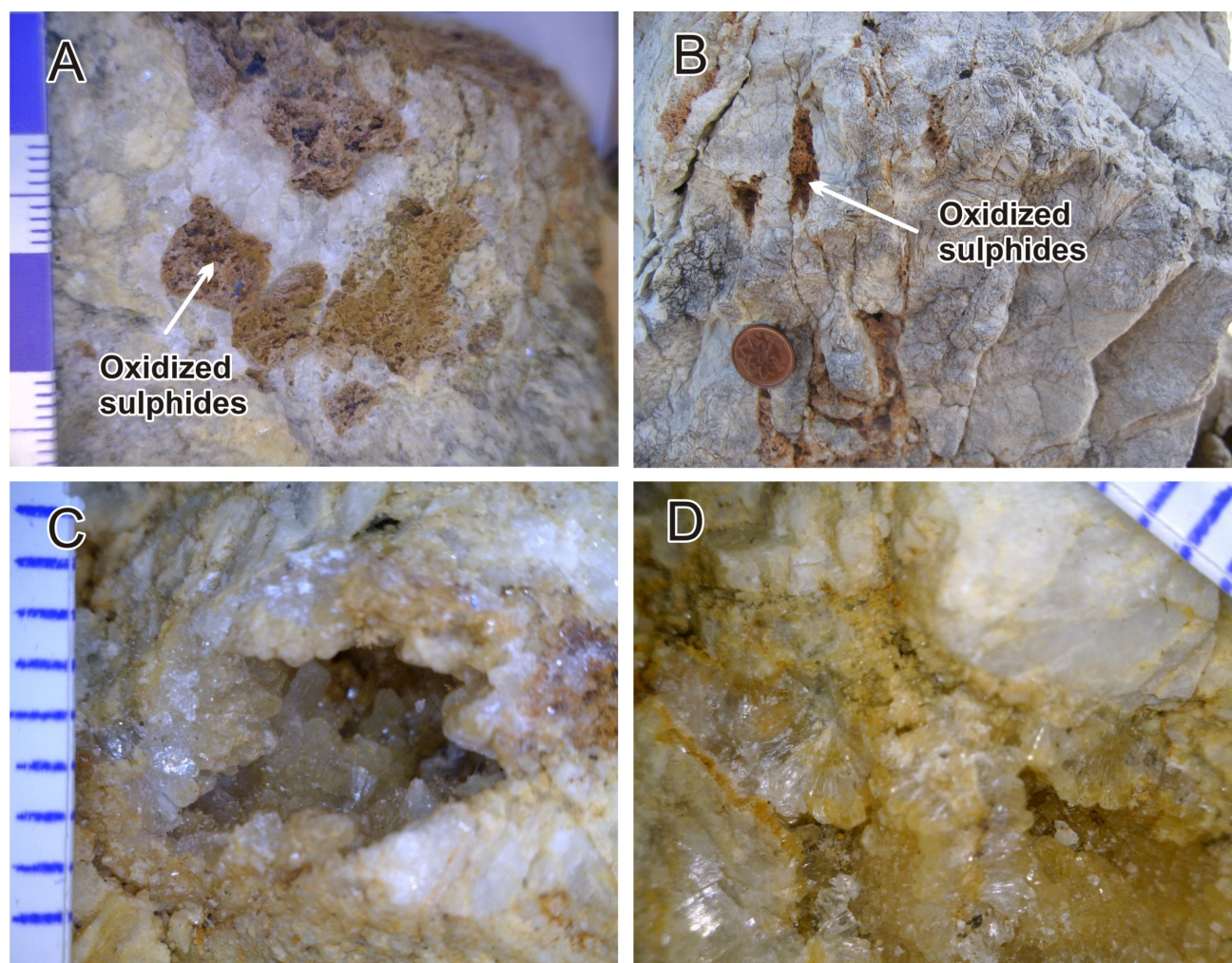


nated blebs, wisps and veinlets of galena were uncovered by the authors during field work, and orange-red sphalerite was observed within a dark grey brecciated dolostone.

### Dolomite Flats

The Dolomite Flats prospect is located approximately 800 m east-southeast of the Flipper Creek occurrence and 600 m northwest of the Main zone. The mineralization is present in several low-relief dome-shaped outcrops, up to 40 by 20 m in size, along the main access road. White to cream, fine- to medium-grained crystalline dolostone is the dominant rock type. The dolostone is characterized by low response to ‘Zinc Zap’ (zinc indicator solution) and weak acid reaction (largely limited to calcite microfracture coatings). The base-metal (Zn-Pb) sulphide and nonsulphide mineralization are confined to the dolostone. The main sulphide minerals are orange-brown to dark grey sphalerite and pyrite that are commonly (at least partially) oxidized

and accompanied by some quartz grains. These are disseminated within the dolostone or occur as fracture fillings (Figure 13A, B). No obvious structural control for the disseminated sphalerite mineralization is visible on the scale of the outcrop; however, at hand-specimen scale, sphalerite appears to be partially controlled by hairline fractures. Nonsulphide minerals typically form soft reddish brown to orange patches that are widespread throughout the fine-grained cream-coloured dolostone (characterized by a weak response to Zinc Zap); they also occur in low concentrations as fine aggregates or minute specks. Where present in above-average concentrations, they form dull fracture coatings and/or sugary textured and porous pods with strong Zinc Zap response. Lead is present in the form of galena as isolated short (<5 cm) and narrow (<2 mm) fracture fillings and small pods (<3 cm). These galena fillings are not common in the outcrops and are rather irregularly distributed.



**Figure 13.** Dolomite Flats prospect, Cariboo Zinc property, east-central British Columbia: **A)** orange-brown patches corresponding to oxidized sulphides disseminated in the dolostone; **B)** fracture-filling oxidized sulphides occasionally forming boxwork texture in the dolostone; **C)** stubby white translucent crystals of hemimorphite lining cavities; **D)** white translucent fan-shaped crystals of hemimorphite lining cavities.



Two grab samples from the Dolomite Flats prospect assayed 0.25% Zn and 0.08% Pb, and 5.6% Zn and <0.02% Pb, respectively (Table 1).

### Main

The Main prospect is exposed in a trench approximately 48 m long and 28 m wide. Another smaller trench is located 230 m northwest of the main trench. Mineralization consists of numerous intersecting 2–3 cm wide quartz veins containing galena and lesser sphalerite and nonsulphide minerals (Figure 14A). Mineralization is largely fracture controlled. The main quartz-galena ( $\pm$ sphalerite $\pm$ nonsulphides) vein system strikes 300–360° and dips east at 60–90°. It crosscuts barren quartz veins (2–3 cm wide) with orientations of 150°/80° W, 135°/50° S and 120°/45° S.

Areas (up to 1 by 0.5 m) consisting largely of massive galena ( $\pm$  euhedral sphalerite and  $\pm$  aggregates of nonsulphide minerals) are present along exposed faces of major fractures within the principal trench of the Main zone (Figure 14B). The fractures are less than 5 cm thick and, as the galena content decreases, quartz content increases. A grab sample from the galena-rich vein breccia system assayed 5.6% Zn and 43% Pb.

### Gunn

Numerous small trenches and larger trenches occur over a 350 by 125 m area south of the dirt road, approximately 150 m southeast of the Main occurrence. Mineralization consists of quartz-galena ( $\pm$ sphalerite $\pm$ nonsulphides) veins and fracture fillings (Figure 15A), barite-galena-sphalerite veins (Figure 15B), pods and irregular replacement zones of oxidized sulphides (Figure 15C), and disseminated fresh and oxidized sphalerite (Figure 15D). The carbonate host is a fine- to medium-grained recrystallized white dolostone.

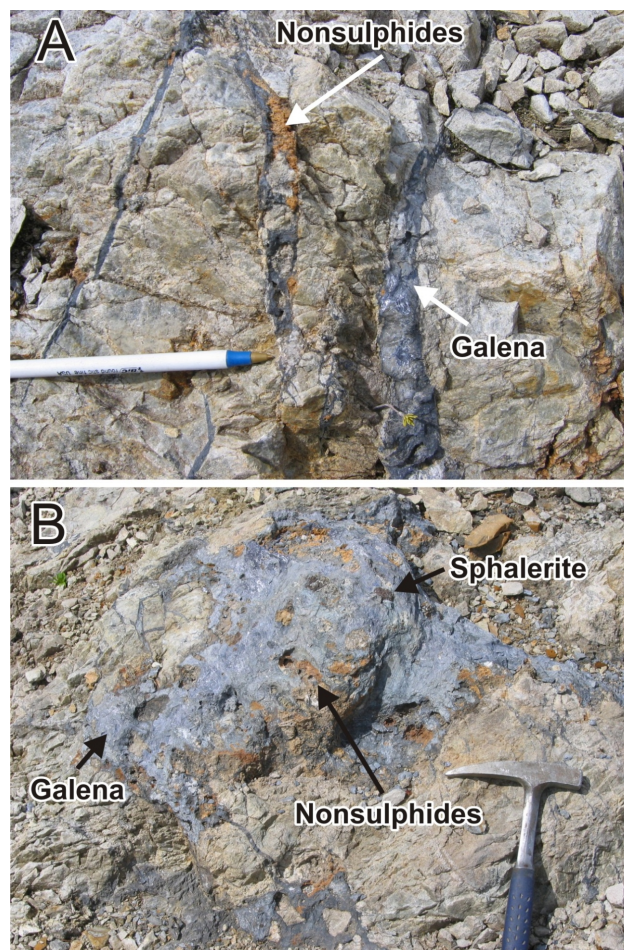
The principal Gunn excavation, located 250 m west of the road, shows a complex network of quartz-galena ( $\pm$ sphalerite $\pm$ nonsulphides) veins enclosed in siliceous cream-coloured dolostone that also locally hosts fine-grained, disseminated, dark grey sphalerite and encloses irregular zones of nonsulphide Zn-Pb mineralization. The veins generally trend north to northwest and dip moderately to steeply (000°/45°E, 280°/67°N, and 300°/80–90°N to 110–130°/46°S). One set of mineralized veins trends 040° and dips 60°SE. Most of the veins are less than 5 cm thick and vary in mineralogy and mineral proportions along strike. They consist of quartz and galena with subordinate amounts of calcite, sphalerite and nonsulphide minerals.

At two locations within the main excavation, Pembroke Mining Corporation and Zincore Metals Inc., geologists reported 16–30% Zn with much lower Pb values across widths of 3–6 m. These zones most likely sampled a combination of vein-type and nonsulphide replacement-type

mineralization. One grab sample of finely disseminated sulphides in dolostone assayed 0.8% Zn and 0.3% Pb.

### Que

The Que showing consists of a large number of shallow exploratory trenches and stripped outcrops and subcrops located at the extreme southeast corner of the Cariboo Zinc property, approximately 750 m south of the Gunn zone. The showing consists of irregularly distributed dolostone-hosted fracture-filled sphalerite, galena and nonsulphide mineralization (Figure 16A, B). Boulders of Zn-bearing nonsulphide mineralization are scattered throughout the area (Figure 16C). At least at one locality, the presence of several large angular and friable nonsulphide-bearing blocks (>1 m in diameter), which strongly react to Zinc Zap, suggests a local origin. White-coated galena (sphalerite-free) nodules up to 4–5 cm across were observed in a north-flowing stream less than 50 m upstream from an occurrence of high-grade nonsulphide-rich boulders. Grab samples from trenches, subcrops and boulders assayed 17.3–51% Zn, 0.14–1.5% Pb, and 0.07–0.76% Fe.



**Figure 14.** Main prospect, Cariboo Zinc property, east-central British Columbia: **A)** quartz-galena-nonsulphide-sphalerite vein; **B)** pod of galena, nonsulphides and sphalerite that form part of a vein-breccia system crosscutting the host dolostone.

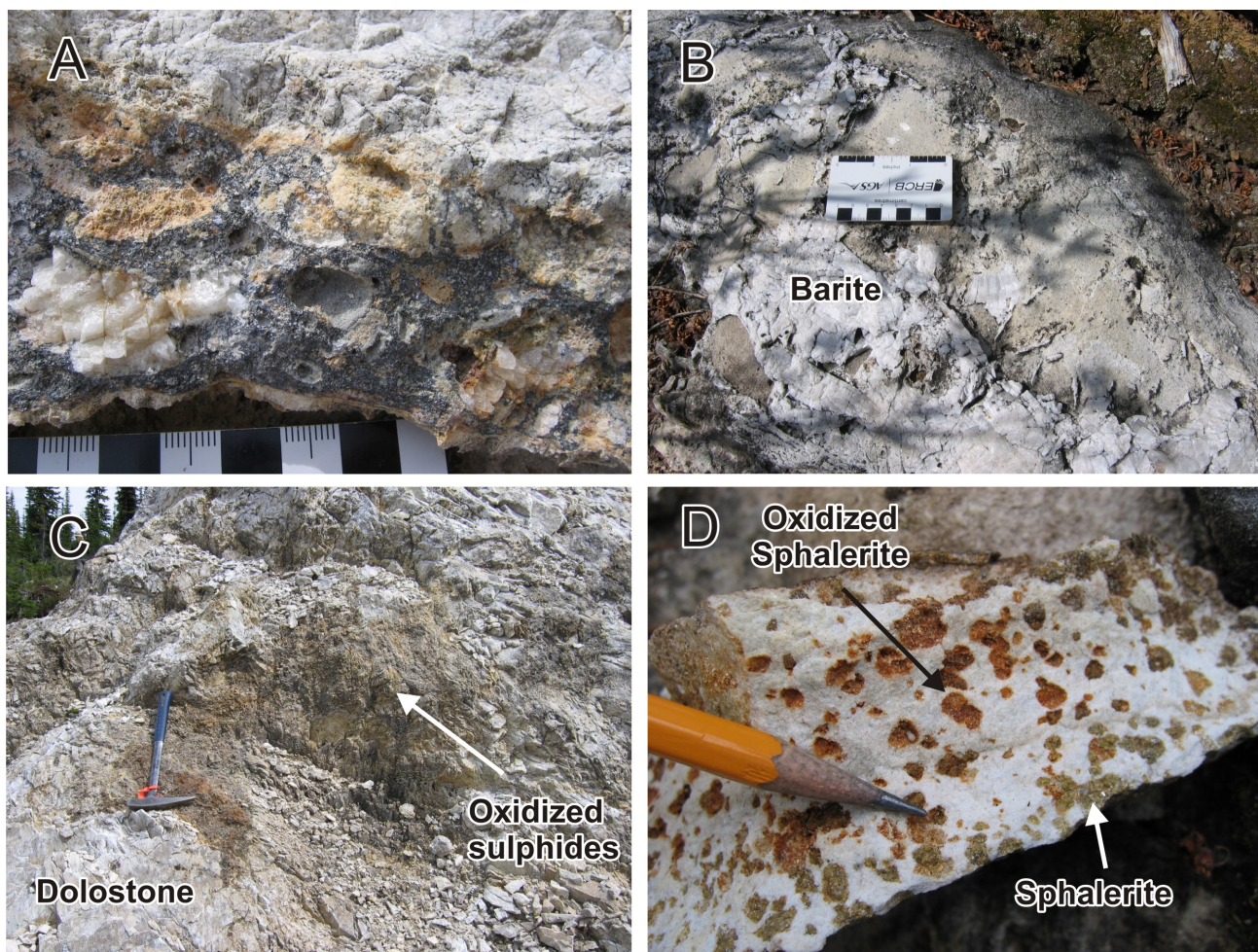


## Samples and Methods

Our work is primarily based on property examinations, limited property-scale mapping, and sampling done in 2007, 2008 and 2009. Before sampling, a rough evaluation of the high-grade zones was made both visually and by testing with Zinc Zap reactant (a solution of 3% potassium ferricyanide  $\{K_3Fe(CN)_6\}$  and 0.5% diethylaniline dissolved in 3% oxalic acid), which causes a bright red colouration on the rocks when zinc is present (Figure 17). This was complemented by petrography, X-ray powder diffraction (XRD) and scanning electron microscope (SEM) analyses, and whole rock geochemistry. Eighty-nine samples were taken from key outcrops from the Redbird, Lomond, Oxide, Jersey and HB properties in the Salmo district of southern BC, and forty samples were collected from key outcrops from the Cariboo Zinc property in the Quesnel Lake area of central BC.

Most of the samples were examined by conventional optical microscopy; however, some were too friable to allow

the preparation of a good thin section and were observed as fragments under a stereoscopic microscope. Approximately 25 samples were analyzed by XRD and SEM at the University of British Columbia Earth and Ocean Sciences microbeam laboratory, to acquire a broad summary of the mineral phases present and record their habits and textural relationships. Finely ground aliquots of sample were smear-mounted onto petrographic slides with anhydrous ethanol and allowed to dry at room temperature. X-ray diffraction data for mineral identification were collected with a scanning step of  $0.04^\circ 2\theta$  and counting time of 2 s/step on a Siemens D5000  $\theta$ - $2\theta$  diffractometer over a range of  $3^\circ$ – $70^\circ 2\theta$  with each scan taking 55 minutes. Minerals were identified with reference to the International Centre for Diffraction Data (ICDD) PDF-4 database using the program DIFFRACplus EVA (Bruker AXS, 2004, Karlsruhe, Germany). The normal-focus Cu X-ray tube was operated at 40 kV and 40 mA.



**Figure 15.** Gunn showing, Cariboo Zinc property, east-central British Columbia: **A)** quartz–galena–nonsulphides ( $\pm$ sphalerite) veins; **B)** barite–galena–sphalerite vein crosscutting the dolostone (only barite is clearly visible in the photograph); **C)** irregular replacement zones of oxidized sulphides in dolostone; **D)** disseminated oxidized (orange) and fresh (yellowish) sphalerite in the fine-grained white dolostone.





**Figure 16.** Que showing, Cariboo Zinc property, east-central British Columbia: **A)** galena veinlets crosscutting nonsulphide-rich dolostone; **B)** fracture filled by coarse-grained dolomite, iron oxyhydroxides, oxidized sulphides (presumably sphalerite) and galena; **C)** large angular nonsulphide-bearing blocks; **D)** translucent radiating tabular crystals of hemimorphite in cavity.

Mineral habits and the textural relationships among minerals were characterized using a Philips XL-30 scanning electron microscope (SEM), equipped with a Bruker Quantax 200 energy dispersive X-ray spectrometer (EDS) system. Backscattered electron imaging was used to observe textural relationships in thin section. EDS was used for the identification of minerals.

Conventional whole-rock geochemical analyses were done on ‘red’ and ‘white’ ores to assess their composition. The analyses were done at ACME Analytical Laboratories Ltd. (Vancouver, BC). Major oxides and several minor elements are reported on a 0.2 g sample analyzed by inductively coupled plasma–emission spectrometry (ICP-ES) following a lithium metaborate/tetraborate fusion and dilute nitric digestion. Loss-on-ignition (LOI) is by weight difference after ignition at 1000°C. Total carbon and total sulphur were done by LECO analysis. High-grade mineralized samples were analyzed by ICP-ES following a hot four-acid digestion for sulphide and silicate ores. Rare earth and refractory elements (e.g., Ba, Co) are determined by inductively coupled

plasma–mass spectrometry (ICP-MS) following a lithium metaborate/tetraborate fusion and nitric acid digestion of a 0.2 g sample. In addition a separate 0.5 g split is di-



**Figure 17.** Typical bright red reaction of Zinc Zap solution in a zinc-rich exposure, east-central British Columbia.



gested in aqua regia and analyzed by ICP-MS to report the precious and base-metal content.

## Mineralogy of the Carbonate-Hosted Nonsulphide Occurrences

### Salmo Camp

The integration of the analytical methods identified the following nonsulphide minerals in the deposits of the Salmo region: Hemimorphite  $\{Zn_4Si_2O_7(OH)_2 \cdot H_2O\}$ , cerussite  $\{PbCO_3\}$ , hydrozincite  $\{Zn_5(CO_3)_2(OH)_6\}$ , and iron oxyhydroxides (goethite  $\{FeO(OH)\}$ , and hematite  $\{Fe_2O_3\}$ ). Among the gangue minerals, dolomite is ubiquitous, followed in abundance by calcite, quartz, iron oxyhydroxides, and traces of anhydrite/gypsum. Remnants of sphalerite and pyrite are noted occasionally. Table 2 lists all observed nonsulphide Zn and Pb minerals occurring with the deposits.

The nonsulphide minerals are paragenetically late and replace the host carbonates and the primary sulphides. They are not deformed and postdate metamorphism and regional deformation of the host rocks. Dolostone, which is an alteration product of the regional limestone, is the primary host rock to the nonsulphide minerals. This dolostone is interpreted as hydrothermal in origin.

The sections at the Red Bird prospect expose high-grade semiconsolidated to consolidated iron-oxide gossan, which replaced the dolostone. Petrographic, XRD and SEM analyses found various iron oxyhydroxides with remnants of goethite, hemimorphite, and remnants of fine-grained pyrite and sphalerite grains in a groundmass of dolomite, calcite, iron oxyhydroxides, and occasional quartz grains. Iron oxyhydroxides occur along fractures and pervasively replaced the carbonate host rock. Hemimorphite is the main nonsulphide mineral at Red Bird. It occurs as translucent white thin tabular crystals and fan-like radiating and concentric aggregates in open spaces, such as secondary pores, intergranular spaces and fractures, and it also pervasively replaces the carbonate groundmass (Figure 18A, B). When present, hydrozincite postdates deposition of hemimorphite and occurs as thin whitish crust on hemimorphite. The fine-grained pyrite and sphalerite are always crosscut and enveloped by a fine layer of iron oxyhydroxides.

The exposures at the Lomond deposit consist of semiconsolidated earthy brown, iron-oxide limonite containing harder areas of goethite. Within the soft earthy limonite are concretions of goethite and rare anglesite-coated nodules of galena. Transparent to translucent crystals of cerussite (0.5–2 mm long) are locally present within the open cavities of goethite (Figure 9).

The iron-oxide gossan at the Jersey-Emerald property consists of goethite, hematite, quartz and minor amounts of

sphalerite and pyrite. No zinc or lead carbonates/silicates were observed.

The oxidized zones sampled at the HB deposit consist of carbonates, quartz, hemimorphite  $\{Zn_4Si_2O_7(OH)_2 \cdot H_2O\}$ , cerussite  $\{PbCO_3\}$ , goethite  $\{FeO(OH)\}$ , hematite, and traces of sulphides (pyrite, galena). Fyles and Hewlett (1959) also mentioned pyromorphite  $\{Pb_5(PO_4)_3Cl\}$ , hopeite  $\{Zn_3(PO_4)_2 \cdot 4H_2O\}$ , spencerite (an uncommon zinc phosphate)  $\{Zn_4(PO_4)_2(OH)_2 \cdot 3H_2O\}$  and tarbuttite  $\{Zn_2(PO_4)(OH)\}$ . The nonsulphide minerals occur as fracture and cavity-filling in a groundmass of carbonate, quartz and iron oxyhydroxides.

The Oxide showing consists of unconsolidated to semiconsolidated limonitic gossans (Figure 5) that contain hemimorphite and minor hydrozincite as the major Zn-bearing minerals. Hemimorphite consists of white and reddish brown fine-grained tabular, botryoidal, colloform, and fan-like radiating and concentric crystals that pervasively replace the carbonate groundmass, and fills cavities and fractures (Figure 18C, D). No sulphides are observed in the samples. Parahopeite  $\{Zn_3(PO_4)_2 \cdot 4(H_2O)\}$ , galena nodules and pyromorphite  $\{Pb_5(PO_4)_3Cl\}$  have also been reported by McAllister (1951).

### Cariboo Zinc Property

The main nonsulphide minerals identified within the Cariboo Zinc property are hemimorphite  $\{Zn_4Si_2O_7(OH)_2 \cdot H_2O\}$ , smithsonite  $\{ZnCO_3\}$ , willemite  $\{Zn_2SiO_4\}$ , cerussite  $\{PbCO_3\}$ , hydrozincite  $\{Zn_5(CO_3)_2(OH)_6\}$ , goethite  $\{FeO(OH)\}$  and hematite  $\{Fe_2O_3\}$ . The gangue minerals are dolomite, calcite, quartz and iron oxyhydroxides. Table 2 lists all the nonsulphide Zn and Pb minerals observed within the deposits. Hemimorphite and willemite are the most common nonsulphide zinc minerals. Willemite is preferentially associated with quartz-galena-bearing veins; whereas, hemimorphite is associated with iron oxyhydroxides as replacement of sphalerite crystals and carbonate groundmass. The nonsulphide minerals are paragenetically late and replace the primary sulphides and the host carbonates. They are not deformed and postdate metamorphism and regional deformation of the host rocks.

Nonsulphide minerals within the Dolomite Flats prospect are typically soft reddish brown to orange, dominated by smithsonite and hemimorphite. These minerals are widespread throughout the fine-grained cream-coloured dolostone in low concentrations as fine aggregates or minute specks. They also form dull fracture coatings and/or sugary textured and porous pods. Locally, the nonsulphides are associated with quartz grains, and visible relicts of sphalerite and pyrite crystals. The most spectacular occurrences of nonsulphides at this locality consist of radiating hemimorphite needles lining cavities (Figure 13C, D). Hemimorphite also occurs as fine delicate euhedral crystals

along fractures of the dolostone (Figure 19A). Smithsonite is inconspicuous in hand specimens but microscopically it grows as fine crystals on a network of crosscutting iron-oxyhydroxide seams (Figure 19B).

The main nonsulphide minerals within the Main prospect are iron oxyhydroxides, hemimorphite and smithsonite, which principally occur as soft reddish brown to orange aggregates in the quartz-galena veins, and in the sulphide pods associated with the vein-breccia system (Figure 14). Microscopically, hemimorphite forms aggregates of euhedral radiating crystals following the iron-oxyhydroxide seams, filling cavities, or replacing the carbonate groundmass (Figure 19C). Smithsonite occurs where hemimorphite prevails as a fine dusting altering sphalerite (Figure 19D). Hydrozincite, present in small amounts, postdates deposition of hemimorphite and smithsonite and occurs as thin whitish crusts on the fine botryoidal concretions of smithsonite.

The nonsulphide minerals at Gunn are principally associated with quartz-galena ( $\pm$ sphalerite) veins and fracture fillings, and some irregular replacement zones in the dolostone. The nonsulphides include hemimorphite, smithsonite, willemite, cerussite, hydrozincite and iron oxyhydroxide. Hemimorphite forms aggregates of white to pale grey, translucent to transparent radiating euhedral crystals, 2–3 mm in length or less altering sphalerite (Figure 19C), filling cavities, and replacing the carbonate groundmass. It also occurs as white transparent crystals, 1.5 mm in length and 0.5 mm in diameter filling cavities. Smithsonite, willemite and cerussite were only observed microscopically. Smithsonite is a grungy looking mineral that is associated with the quartz-galena ( $\pm$ sphalerite) veins. Willemite occurs as aggregates of granular crystals forming discontinuous rims around galena crystals in the veins (Figure 19E). Cerussite occurs in very small amounts (<1%) in the samples and is associated with microfractures of galena and iron oxyhydroxide.

Two types of nonsulphide occurrences are found at Que: 1) dolostone outcrops with microfractures and veinlets of iron oxyhydroxide, nonsulphides, and remnants of galena, sphalerite and pyrite crystals; and 2) scattered high-grade boulders of Zn-bearing nonsulphide mineralization. Hemimorphite can be found in both types of occurrences. It is the principal nonsulphide mineral altering sphalerite and occurs as scattered crystals along the iron-oxyhydroxide microfractures. In the boulders, it forms massive aggregates of coarse-grained euhedral radiating crystals (Figure 19F). Hydrozincite forms a thin white crust on the hemimorphite-rich samples.

## Discussion

Two distinct types of carbonate-hosted, nonsulphide base-metal (CHNSBM) mineralization occur within the Salmo

camp: 1) the mineralization exposed at the surface of the Red Bird, Lomond, HB and Jersey-Emerald properties consist predominantly of red ore, and 2) the mineralization exposed at the surface of the Oxide prospect is characterized by white ore. The dominant mineralogical phases of the red ore are iron oxyhydroxides and hemimorphite replacing both primary sulphides and carbonate host rocks. Cerussite, smithsonite and hydrozincite are locally present. Remnants of primary sphalerite, pyrite and galena are present at all showings. Intergrowth crystals of dolomite (70–90%) and calcite (30–10%), and occasional quartz form the gangue minerals, and rhombohedral and scalenohedral calcites are also observed as newly formed phase-filling cavities and fractures. Based on historical descriptions, the white ore of the Oxide prospect is made of soft earthy material containing predominantly hemimorphite, minor amounts of iron oxyhydroxides, and rare nodules of galena. McAllister (1951) and Fyles and Hewlett (1959) also reported the local presence of pyromorphite and parahopeite. The underground workings at Oxide are not accessible; however, hemimorphite-rich material is found commonly as rounded or ovoid-shaped, dense but porous masses in unconsolidated overburden. These masses are beige to pale gray in colour, hard but porous and characterized by intricate (commonly concentric) system of pores. No remnants of sulphides have been observed within these masses.

The mineralogical and geological characteristics (i.e., CHNSBM zones underlain by sulphide mineralization) of the nonsulphide Zn-Pb mineralization at Red Bird, Lomond, HB and Jersey point to supergene direct-replacement of the sulphide-rich protore. During the formation of a direct-replacement CHNSBM deposit, primary ore (protore) is oxidized, and base metals pass into solution and are redistributed and trapped within space originally occupied by the protore (Simandl and Paradis, 2009). Depending on the extent of replacement of sulphides by base-metal and iron-bearing nonsulphide minerals (oxides, silicates, carbonates and phosphates), the resulting ore is called mixed (combination of sulphide and nonsulphide ore) or nonsulphide ore (also referred to as oxide ore). The geological and mineralogical evidence suggests that the Zn-rich white ore mineralization at Oxide may be of supergene wallrock-replacement type (Simandl and Paradis, 2009). In this system, the base metals liberated by the oxidation of sulphides are not trapped locally (as for the red ore), but they are transported by percolating waters down and away from the sulphide protore and precipitated under more reducing conditions (cf. Hitzman et al., 2003). In this particular case, because the deposit is located at the contact of carbonate with quartzite, high activity of silica was probably the determining factor in crystallization of hemimorphite rather than smithsonite-rich ore. Wallrock-replacement deposits can be located in proximity to protore or several

**Table 2.** Most common minerals occurring within properties of the Salmo camp and the Cariboo Zinc property, east-central British Columbia.

Sample no.	Location <sup>1</sup>	Deposit	Zone	Rock type	Minerals	Texture
C-473745A	5429233N, 471306E	Red Bird	Beer Bottle, zone B, Trench B-2000-01	nonsulphide-rich dolostone	Fe-Ox, do, cc, he, qz, possible sph(?)	nonsulp replace carb groundmass and fills cavities; cg clear calcite fills cavities
C-473745B	5429233N, 471306E	Red Bird	Beer Bottle, zone B, Trench B-2000-01	nonsulphide-rich dolostone	do, cc, qz, Fe-Ox, traces of sph	nonsulp replace carb groundmass and fills cavities; qz fills cavities, seams, veinlets and present in groundmass
C-473745C	5429233N, 471306E	Red Bird	Beer Bottle, zone B, Trench B-2000-01	nonsulphide-rich dolostone	he, Fe-Ox, traces of py, sph(?)	he in porous aggregates of Fe-Ox; he replaces groundmass
2007-SP-019-1	5429240N, 471308E	Red Bird	Beer Bottle, zone B, Trench B-2000-01	iron-oxide gossan	Fe-Ox, sulph (py, sph?)	Fe-Ox breccia with remnants of sulph
2007-SP-020-1	5429349N, 471420E	Red Bird	Beer Bottle, zone B, Trench B-2000-01	iron-oxide gossan	carb, Fe-Ox, nonsulp	nonsulp disseminated in carb groundmass and associated with Fe-Ox veinlets/seams
09-SP-170	5429240N, 471314E	Red Bird	Beer Bottle, zone B, Trench B-2000-01	weathered dolostone	do, Fe-Ox	no sulph and nonsulp
09-SP-171	5429240N, 471314E	Red Bird	Beer Bottle, zone B, Trench B-2000-01	grey sand	qz, carb, Fe-Ox, sulph, rock fragments	unconsolidated sand
09-SP-173	5429240N, 471314E	Red Bird	Beer Bottle, zone B, Trench B-2000-01	weathered weakly mineralized dolostone	do, Fe-Ox (py?)	Fe-Ox along microfractures and carb cleavages
09-SP-174	5429240N, 471314E	Red Bird	Beer Bottle, zone B, Trench B-2000-01	nonsulphide-rich dolostone	nonsulp, Fe-Ox, qz, cc, traces of sph	nonsulp replaces carb groundmass and sulph
09-SP-178	5429240N, 471314E	Red Bird	Beer Bottle, zone B, Trench B-2000-01	weathered weakly mineralized dolostone	do, cc, qz, Fe-Ox, nonsulp	Fe-Ox and nonsulp fill fractures/veinlets, which crosscut qz vein; nonsulp also in cavities and carb groundmass
09-SP-183-2	5429240N, 471314E	Red Bird	Beer Bottle, zone B, Trench B-2000-01	iron-oxide gossan	Fe-Ox with remnants of go	porous, friable Fe-Ox-rich sample
09-SP-190	5429388N, 471447E	Red Bird	Zone C, Trench C 2000-01	weakly mineralized limestone	carb, minor nonsulp, micas, qz	nonsulp are between carb grains
09-SP-191	5429388N, 471447E	Red Bird	Zone C, Trench C 2000-01	nonsulphide-rich dolostone	do, he	he fill cavities and microfractures
09-SP-192	5429388N, 471447E	Red Bird	Zone C, Trench C 2000-01	greenish beige sand	do, he, minor sulph	he along fractures/veins and in cavities
09-SP-193	5429388N, 471447E	Red Bird	Zone C, Trench C 2000-01	weakly mineralized dolostone	do, minor Fe-Ox, qz, nonsulp	nonsulp associated with Fe-Ox along fractures and occur in cavities
09-SP-196	5429388N, 471447E	Red Bird	Zone C, Trench C 2000-01	weakly mineralized dolostone	do, Fe-Ox, nonsulp, traces of sph	nonsulp along Fe-Ox seams and in cavities; few small resorbed sph crystals
09-SP-201	5429388N, 471447E	Red Bird	Zone C, Trench C 2000-01	mineralized dolostone	do, cc, Fe-Ox, nonsulp(?), traces of sph(?)	sulph grains diss along styloliths/fractures
09-SP-203	5429388N, 471447E	Red Bird	Zone C, Trench C 2000-01	mineralized dolostone	do, cc Fe-Ox, qz, nonsulp(?), sph	nonsulp occur as fine acicular cx along Fe-Ox-filled microfractures; remnants of sph
09-SP-204	5429388N, 471447E	Red Bird	Zone C, Trench C 2000-01	nonsulphide-rich dolostone	do, cc, Fe-Ox, he, qz, sph	nonsulp along Fe-Ox-filled microfractures and agg replacing carb groundmass; cavities filled by cg clear cc
2008-GS-22A	5427787N, 475355E	Lomond		iron-oxide gossan	go, hem, nonsulp, tr py, sph	massive hem, goethite with cavities partially filled by nonsulp
2008-GS-22C	5427787N, 475355E	Lomond		iron-oxide gossan	go, ce	ce in cavities of goethite
2008-SP-85	5457482N, 489475E	Oxide		nonsulphide-rich dolostone	he	nonsulp fill cavities and replace carb groundmass
2008-SP-87	5457719N, 489516E	Oxide		nonsulphide-rich dolostone	he, Fe-Ox, sph(?)	nonsulp replaces carb groundmass and sulph; remnants of sph(?)



Table 2 (continued)

Sample no.	Location <sup>1</sup>	Deposit	Zone	Rock type	Minerals	Texture
2008-SP-88	5457365N, 489966E	Oxide		nonsulphide-rich dolostone	he	massive replacement by he
2008-SP-88B	5457365N, 489966E	Oxide		nonsulphide-rich dolostone	go	massive go
08-SP-104A	5439662N, 483892E	Jersey		iron-oxide gossan	py, sph, qz, Fe-Ox, traces of nonsulp, tr of gyp/anh	layered massive sulphides with occ nonsulp altering sph
08-SP-105	5439963N, 484104E	Jersey		iron-oxide gossan	go	Fe-Ox-rich sample with remnants of go
2008-GS-15	5444589N, 485465E	HB		iron-oxide gossan	Fe-Ox, carb, nonsulp (he, cs), traces py	nonsulp fill cavities, fractures and replace groundmass of Fe-Ox and carb
2008-GS-15A	5444589N, 485465E	HB		iron-oxide gossan	go, qz	Fe-Ox-rich sample with go layers; qz fill cavities
C-534856	5445011N, 485621E	HB		nonsulphide-rich dolostone	Fe-Ox (hem, go), qz, carb, minor py, ga	Fe-Ox, qz, carb form groundmass; remnants of py, ga
09-SP-220A	5853965N, 641517E	Cariboo Zinc	Dolomite Flats	dolostone	do, cc	fine- to medium-grained massive dolostone
09-SP-220B	5853965N, 641517E	Cariboo Zinc	Dolomite Flats	mineralized dolostone	do, cc, sph, mica, nonsulp(?)	sphalerite along microfractures
09-SP-221	5853951N, 641596E	Cariboo Zinc	Dolomite Flats	mineralized dolostone	do, nonsulp, mica, sph	nonsulp along microfractures and occ partially replace sph
09-SP-221A	5853951N, 641596E	Cariboo Zinc	Dolomite Flats	nonsulphides	do, Fe-Ox, nonsulp, py	nonsulp along microfractures and walls of cavities; remnants of py enveloped by Fe-Ox
09-SP-221B	5853951N, 641596E	Cariboo Zinc	Dolomite Flats	nonsulphides	do, Fe-Ox, sm, py, sph(?)	nonsulp and Fe-Ox form mat along microfractures and around cavities; remnants of sph and py
09-SP-222A	5854015N, 641702E	Cariboo Zinc	Dolomite Flats	nonsulphides	do, Fe-Ox, nonsulp, sph, mica	nonsulp fill cavities; and replace carb groundmass
09-SP-222B	5854015N, 641702E	Cariboo Zinc	Dolomite Flats	dolostone	do, qz	fine-grained dolostone
09-SP-224B	5853582N, 641791E	Cariboo Zinc	Main Zone	mineralized dolostone	do, Fe-Ox, sm, sph, py	nonsulp assoc. with Fe-Ox microfractures and replace carb groundmass; remnants of py, sph
09-SP-225B	5853400N, 641939E	Cariboo Zinc	Main Zone	nonsulphides-ga-qz vein	Fe-Ox, ga, carb, nonsulp	nonsulp present along cavity walls and fill cavities; grow along Fe-Ox and altered ga
09-SP-227	5852378N, 643555E	Cariboo Zinc	Gunn zone	weathered mineralized dolostone	qz, carb, sph, nonsulp	nonsulp replace sph cx along borders
09-SP-228	5852385N, 643548E	Cariboo Zinc	Gunn zone	mineralized dolostone	qz, carb, nonsulp, sph, py, ga?	nonsulp diss in groundmass and replacing sph along borders
09-SP-230	5852259N, 643479E	Cariboo Zinc	Gunn zone	nonsulphide-rich dolostone	sm, he	nonsulp replace groundmass, fill cavities and alter ga
09-SP-231A	5852188N, 643413E	Cariboo Zinc	Gunn zone	qz-ga-nonsulphides vein	do, qz, Fe-Ox, ce, sph, ga	nonsulp partially replaced carb, sph and ga
09-SP-231D	5852188N, 643413E	Cariboo Zinc	Gunn zone	qz-ga vein	do, qz, ga, ce(?)	nonsulp rim ga and occur in cavities of ga veinlets
09-SP-231E	5852188N, 643413E	Cariboo Zinc	Gunn zone	qz-ga-nonsulphides vein	carb, qz, Fe-Ox, nonsulp, ga	nonsulp assoc. with ga and Fe-Ox in veinlets
09-SP-231F	5852188N, 643413E	Cariboo Zinc	Gunn zone	iron-oxide gossan	Fe-Ox, nonsulp, py	nonsulp assoc. with Fe-Ox seams; few remnants of py surrounded by Fe-Ox
09-SP-237A	5851520N, 644120E	Cariboo Zinc	Que zone	nonsulphide-rich dolostone	he, Fe-Ox, qz, sph (do?)	massive he replacement of carb and sulph
09-SP-237C	5851520N, 644120E	Cariboo Zinc	Que zone	mineralized dolostone	carb, Fe-Ox, nonsulp, sph, py	nonsulp along Fe-Ox-filled microfractures, form veinlets and replace sph; remnants of sph, py
09-SP-240B	5851503N, 644162E	Cariboo Zinc	Que zone	mineralized dolostone	carb, ga, nonsulp	nonsulp assoc. with ga veinlets
09-SP-242	5851843N, 643242E	Cariboo Zinc	Que zone	nonsulphide-rich dolostone	do, he, Fe-Ox, sulph, hy	nonsulp replace carb and sulph
09-SP-243	5851843N, 643242E	Cariboo Zinc	Que zone	nonsulphide-rich dolostone	do, he, Fe-Ox, sulph, hy	nonsulp replace carb and sulph

Abbreviations: agg, aggregates; anh, anhydrite; carb, carbonates; cc, calcite; ce, cerussite; cg, coarse grained; cx, crystals; do, dolomite; Fe-Ox, iron oxyhydroxides; ga, galena; go, goethite; gyp, gypsum; hem, hematite; he, hemimorphite; hy, hydrozincite; nonsulp, nonsulphides; occ, occasional; qz, quartz; sm, smithsonite; py, pyrite; sph, sphalerite; sulph, sulphides, tr, traces; wl, willemite

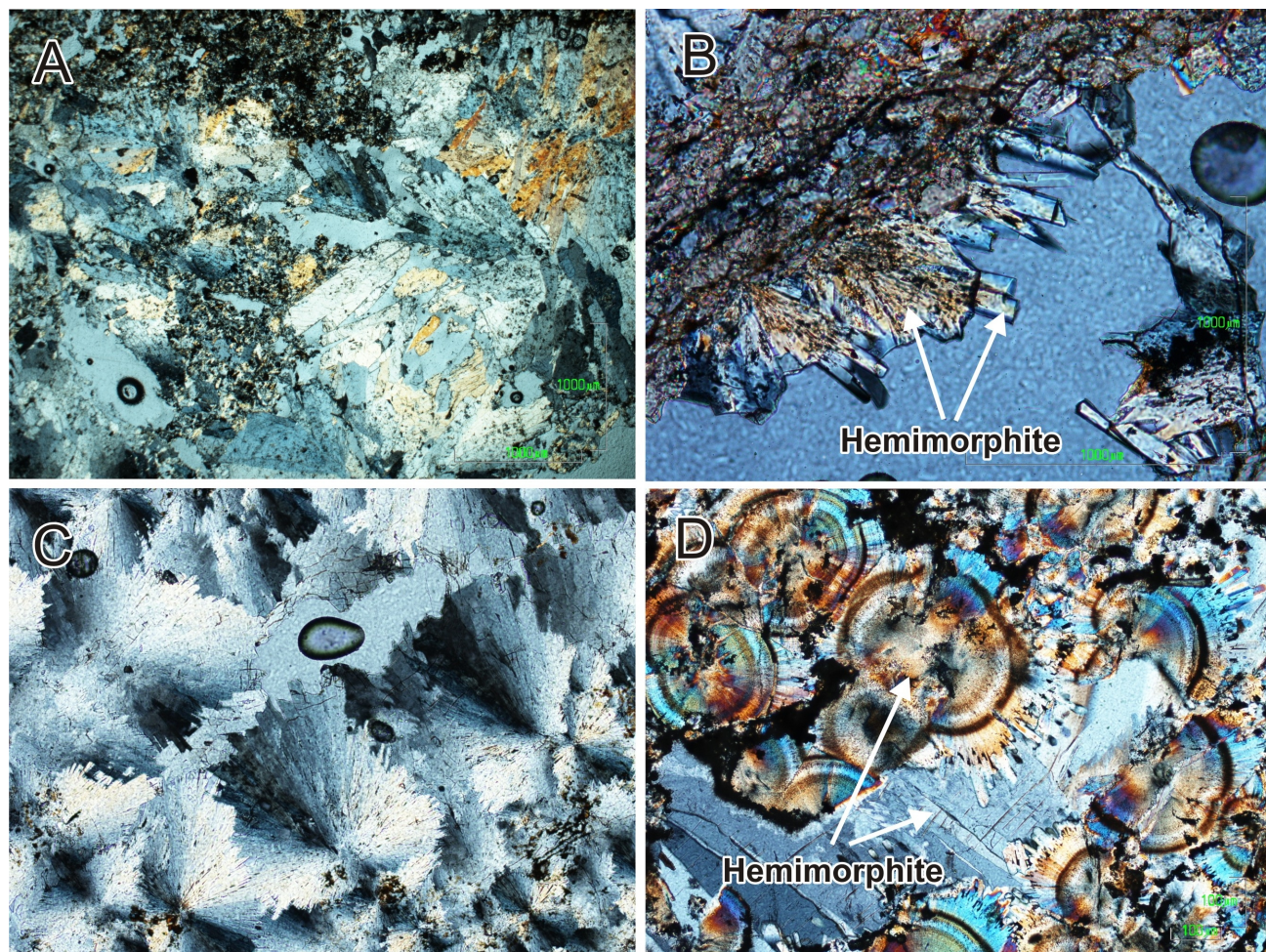
<sup>1</sup>Coordinates are given in Universal Transverse Mercator (UTM) projection, North American Datum 1983.



hundreds of metres away (Heyl and Bozior, 1962; Hitzman et al., 2003; Reichert and Borg, 2008).

The carbonate-hosted sulphide and nonsulphide mineralization of the Cariboo Zinc property occurs as disseminations of fine specks and centimetre-size aggregates, irregular replacement zones, and veins and fracture fillings locally forming narrow breccia zones. Sphalerite occurs mostly as pervasive fine- to medium-grained, low-grade disseminations in dolostone; aggregates forming centimetre-size clots; and, less frequently, fracture and breccia fillings. Galena occurs mainly as fracture and vein fillings in association with quartz and/or calcite, sphalerite and barite. Galena-rich crackle and mosaic dolostone breccias ( $\pm$  sphalerite) are less common. In all of the occurrences, galena and sphalerite are at least partially or totally transformed into Zn-Pb nonsulphides. The dominant nonsulphide minerals are hemimorphite and smithsonite, with variable amounts of iron oxyhydroxides and hydrozincite. Willemite and cerussite were recognized only at

Gunn and Que occurrences. The nonsulphides form millimetre-scale orange patches, oxide boxworks (after sphalerite), open-space fillings, and irregular replacement pods and masses with or without remnants of sphalerite, galena and pyrite. Hemimorphite and smithsonite replace sulphides and host carbonates, but willemite and cerussite only replace the sulphide assemblages. Our preliminary observations suggest that hemimorphite and smithsonite developed at the expenses of willemite and cerussite in near-surface oxidation of the sulphides. They have all the characteristics of supergene oxidation products, whose physicochemical conditions of formation remain unclear. Surprisingly, iron sulphides (pyrite and/or marcasite) are present in low concentrations throughout the area, with the exceptions of the DeBasher and Dolomite Flats occurrences, where pyrite is found associated with aggregates of sphalerite. This is significant because under oxidizing conditions, pyrite is more reactive in surface environments than sphalerite or galena. The best and highest grade nonsulphide mineralization within the Cariboo Zinc prop-

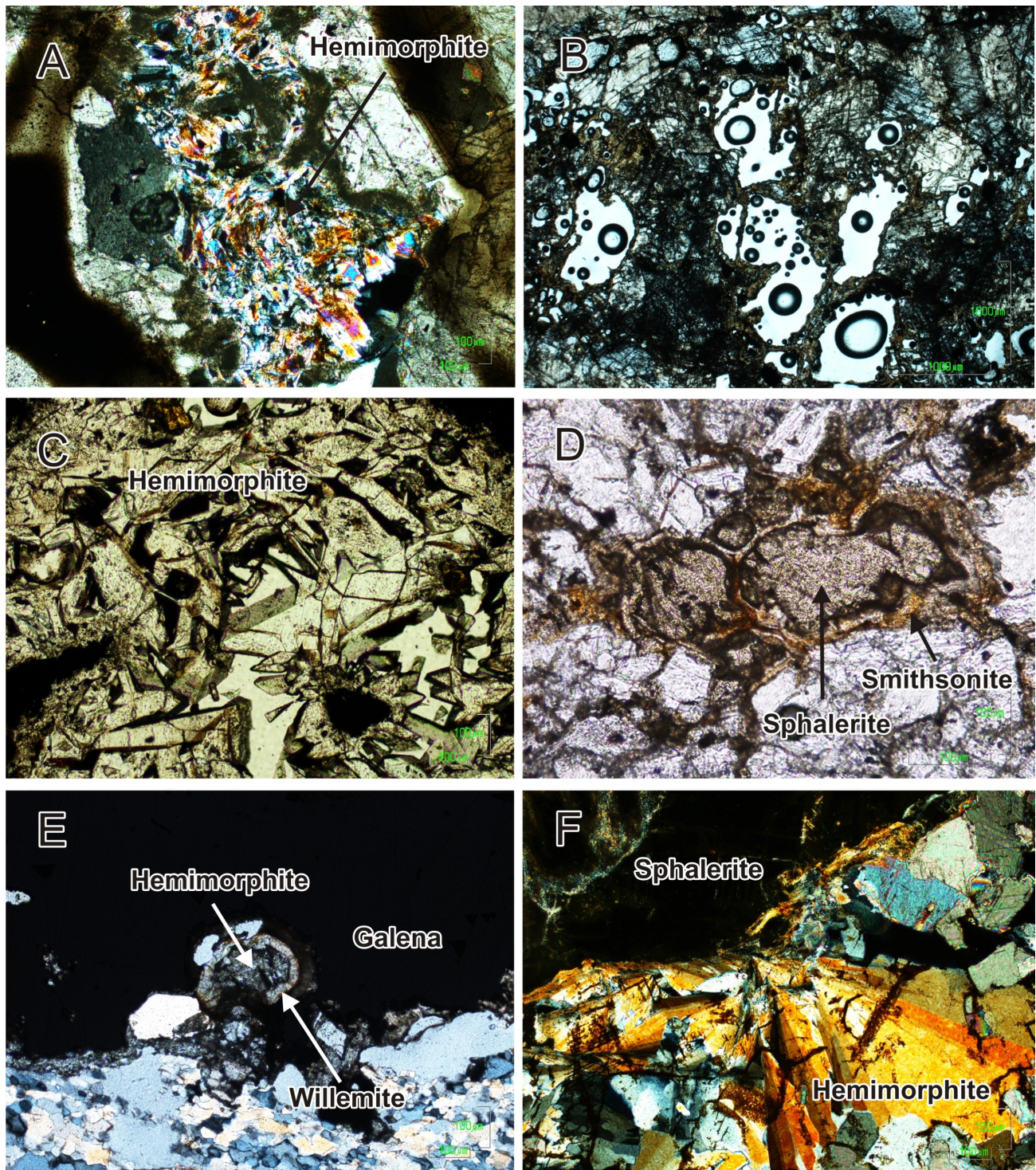


**Figure 18.** Microphotographs taken under crossed polar light of Zn and Pb nonsulphide minerals from the Red Bird and Oxide deposits, east-central British Columbia: **A)** aggregates of tabular crystals of hemimorphite replacing the carbonate host rock; **B)** tabular crystals of hemimorphite lining cavities; **C)** aggregates of fine radiating crystals of hemimorphite pervasively replacing the carbonate groundmass; **D)** two generations of hemimorphite: concentric aggregates of radiating crystals; and coarse-grained tabular crystals.



erty is found within subcrops and large angular boulders of nonsulphide mineralization scattered throughout the Que showing area. Three grab samples assayed 51% Zn, 43.3%

Zn, and 17.32% Zn with low concentrations of Pb and Fe (Table 1).



**Figure 19.** Microphotographs of Zn and Pb nonsulphide minerals from the Cariboo Zinc property, east-central British Columbia: **A)** Dolomite Flats showing, fine euhedral crystals of hemimorphite following the iron-oxyhydroxide microfractures in the dolostone, crossed polars; **B)** fine-grained aggregates of smithsonite forming a crosscutting network in the dolostone, crossed polars; **C)** aggregates of euhedral crystals of hemimorphite, plane-polarized light; **D)** smithsonite altering sphalerite, plane-polarized light; **E)** willemite forming a rim around galena, crossed polars; **F)** aggregates of radiating hemimorphite crystals altering sphalerite and replacing carbonates, crossed polars.



In summary, the nonsulphide mineral occurrences and assemblages within the Salmo district and the Cariboo Zinc property are different; however, in both cases they fit the supergene model described by Simandl and Paradis (2009).

### Ongoing Work and Applied Research Aiming to Help the Exploration Community

The characterization of the nonsulphide deposits of southern and central BC is essential for the formulation of integrated exploration programs targeting CHNSBM deposits in BC and elsewhere. Zinc or lead oxides, silicates and carbonates are also indirect indicator minerals in exploration for MVT, SEDEX, Irish-type, and vein-type Zn-Pb deposits (i.e., Zn-Pb sulphide precursors to CHNSBM deposits). The potential for nonsulphide deposits in BC is good regardless of the intensity of the glaciation. The orientation of the nonsulphide mineralization is a key factor. Steeply plunging, rod-shaped nonsulphide oxide deposits (such as those of the Salmo camp), with their smallest dimension exposed at surface, enclosed in competent rocks (i.e., dolomitized limestone), have the best preservation potential. Flat-lying exposed deposits, with the largest dimensions coplanar with erosion surfaces, have lower survival potential. The compact hemimorphite-rich masses within the overburden at the Oxide deposit suggest that, small-scale glacial transport of the nonsulphide material from steeply plunging CHNSBM bodies increases the footprint of the exploration target.

Preliminary results of portable XRF tests conducted on nonsulphide ores indicate that this technology could greatly facilitate exploration for nonsulphide deposits, since white ores are notoriously difficult to recognize by traditional prospecting methods (Simandl and Paradis, 2009; S. Paradis and G.J. Simandl, work in progress).

Characterization of the physical properties of the nonsulphide Zn, Pb, Fe oxides, carbonates and silicates is essential for evaluation/selection of geophysical methods in exploration for nonsulphide Pb-Zn deposits. To the best of our knowledge, such data is not available in the literature; and a sister publication to this document by Enkin et al. (2011) will be the first one of its kind.

### Acknowledgments

Geoscience BC is acknowledged and thanked for the funding provided for this project. The authors extend their appreciation to A. Troup and E. Lawrence of Sultan Minerals Inc., Pembrook Mining Corporation; L. Addie, President of the Chamber of Mines of Eastern BC; and B. Findlay and J. Barquet of Dajin Resources Corp. for sharing their knowledge of the area and permitting us to sample drillcore intersections and surface exposures. Three samples from the HB and Red Bird occurrences were given by B. Richards of the GSC. Earlier version of this manuscript bene-

fited from review of G. Dipple of the University of British Columbia. The authors were assisted in the field by H. Mills of the University of Alberta, A. Duffy, a graduate from Trinity College, Dublin (Ireland), and L. Simandl from St. Michaels University School, Victoria. This project started under the umbrella of the Cordilleran Targeted Geoscience Initiative Program (TGI-3) of the Geological Survey of Canada, and was done in collaboration with the BC Ministry of Forests, Mines and Lands.

Natural Resources Canada, Earth Science Section contribution 20100304.

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